Low Back Position Awareness in People With and Without Recurrent Non-Specific Low Back Pain

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ABSTRACT

This thesis investigates position awareness of the low back, measured using an electrogoniometer, in participants with and without recurrent non-specific low back pain (NSLBP).

The ability to appreciate body position and movement makes an essential contribution to control of posture and functional movement. Pain may impair this awareness and initiate or exacerbate joint damage. Impairment of position awareness in the low back has been reported in patients with chronic low back pain. In addition, work-related activities may impair positional awareness, particularly in people experiencing LBP.

The accuracy, stability and through range test-retest reliability of the electrogoniometer was assessed. It was found to be a reliable measure of degrees during movement in the sagittal plane between 0 to +/- 60 degrees, when compared to measurements using a calibrated, highly accurate, bevel protractor (mean error differences below 0.5 degrees for all tests).

Low back position awareness was measured before and after a shift of work, in sitting and standing, in 61 people with recurrent NSLBP and 40 without a history of LBP. In addition, secondary analysis investigated the effect of occupation (manual workers, sedentary workers, drivers) on position sense. Low back position awareness was also measured in 50 people with recurrent NSLBP and 50 without a history of LBP during mid-range of sagittal plane movement of the low back in sitting; and when trying to return to a “good” sitting posture.

There were no differences between participants with and without recurrent NSLBP in repositioning accuracy of the low back during any of the studies. When investigating the effect of occupation however, only sedentary workers achieved the power required for analysis. Participants with and without LBP had greatest difficulty returning to their neutral low back sitting posture, both before and after a shift of

work. People with LBP positioned their “good” sitting posture significantly closer to end-range of low back extension, than people without LBP (12.47 SD8.46, v’s 16.51 SD9.41 degrees respectively; P=0.026).

Recurrent NSLBP and sedentary work-related activities did not affect accuracy of position awareness in the low back. In people with recurrent NSLBP however, the position of their “good” sitting posture closer to end-range low back extension could lead to greater compressive loading of pain-sensitive spinal tissue, as well as increases in facet joint forces and shear forces on discs. These mechanisms may be aetiologic in the recurrence and maintenance of LBP. This finding may have implications for clinical practice, with consideration perhaps given to assessing the position of “good” sitting posture and its relationship to end-range in patients with LBP. Future research should investigate this further in larger populations of people with and without LBP, including specific sub-groups of LBP.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGMENTS

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I would like to thank Michael Hurley PhD, Professor of Physiotherapy, Faculty of Health and Social Care Sciences, St George's, University of London - primary supervisor; Lisa Roberts PhD, Faculty of Health Sciences, University of Southampton - secondary supervisor; Mark Mullee MSc, Director & Senior Lecturer in Medical Statistics, Research Design Service, University of Southampton; Martin Warner PhD, Experimental Officer, Centre for Innovation and Leadership in Health Sciences, Faculty of Health Sciences, University of Southampton.

I would also like to thank all the participants involved in the study.

Finally, I would like to thank my family for their patience and support.

ABBREVIATIONS AND GLOSSARY OF TERMS USED IN THE THESIS

Aα = A alpha

ACL = anterior cruciate ligament

Aγ = A gamma

BMI = body mass index

CNS = central nervous system

EEG = electroencephalography

EMG = electromyography

fMRI =functional magnetic resonance imaging

GCPS = graded chronic pain scale

GTO = Golgi tendon organ

ICC = intraclass correlation coefficient

LBP = low back pain. The participants in this thesis are referred to as people or participants with LBP. In this context the participants with LBP had recurrent non-specific LBP that was defined as:

- pain between the lowest ribs and gluteal folds (Smedley, Egger, Cooper, & Coggon, 1997)
- with or without referral into the legs
- LBP not attributable to a recognisable, known specific pathology i.e. several structures may contribute to the LBP, such as the joints, discs and connective tissue (Airaksinen et al., 2006; NICE, 2009; van Tulder et al., 2006)
- a painful episode in the previous 3 months lasting greater than 24 hours (Smedley et al., 1997)
- a previous history of at least one other episode of LBP (Little et al., 2008) lasting greater than 24 hours
- and at least one episode in the past that has necessitated medical advice on at least one occasion.

LF-MPQ = long-form McGill pain questionnaire

LREC = local regional ethics committee

MVC = maximum voluntary contraction

NLBP = no low back pain

NSLBP = non-specific low back pain

Position awareness = relates to the sense of position.

Position sense = relates to the sense of position.

PPEF = private physiotherapy educational foundation

PPI = present pain index

Proprioception = The afferent (incoming) part of the sensorimotor system and is a variant of the sense of touch, relating to the senses of position (position sense) and movement of body parts. A more detailed definition suggests it is the conscious and unconscious perception of body position, movement (Sharma, 1999), velocity, acceleration (Swinkels & Dolan, 2000) and the force, effort, heaviness and timing associated with muscular contraction (Gandevia, McCloskey, & Burke, 1992).

Proprioceptive acuity = accuracy of position sense

RDQ = Roland Disability Questionnaire

Reposition error = error in position sense

SD = standard deviation

2xSD = two times standard deviation

SF-MPQ = short-form McGill Pain Questionnaire

SF-36 = short-form health survey

SIP = sickness impact profile

SRM = standardised response mean

TMS = transcranial magnetic stimulation

TrA = transversus abdominus

VAS = visual analogue score

95% CI = 95% confidence interval

INTRODUCTION TO THESIS

Motivation for the research

Low back pain (LBP), is defined as pain between the lowest ribs and the gluteal folds (Smedley et al., 1997), with or without referral into the legs. The participants with LBP in this thesis had recurrent non-specific LBP (NSLBP) that was further defined as LBP not attributable to a recognisable, known specific pathology i.e. several structures may contribute to the LBP, such as the joints, discs and connective tissue (Airaksinen et al., 2006; NICE, 2009; van Tulder et al., 2006); a painful episode in the previous 3 months lasting greater than 24 hours (Smedley et al., 1997); a previous history of at least one other episode of LBP (Little et al., 2008) lasting greater than 24 hours; and at least one episode in the past that has necessitated medical advice on at least one occasion. It is acknowledged however, that there is large variation in the definition of "recurrent" LBP used in the literature. A consensus for a standardised definition of recurrent LBP is needed to enable appropriate comparisons between studies (Stanton, Latimer, Maher, & Hancock, 2010).

In addition, the high number of people with recurrent LBP, makes it difficult to distinguish between people with chronic and acute LBP. None of six systematic reviews on epidemiology between 1999 and 2003, that informed the European Guidelines for the Management of Chronic Non-Specific LBP gave specific prevalence rates for acute, chronic, recurrent or non specific LBP (Airaksinen et al., 2006).

Low back pain is a complex, multidimensional, biopsychosocial problem. Although research has advanced knowledge and management of the condition, significant gaps remain in diagnosis and treatment, with epidemiological studies suggesting the prevalence and socio-economic consequences are not lessening (Dodd, 1997; Maniadakis & Gray, 2000).

In 1995, 40% of the adult population reportedly experienced back pain during the year, with 51% of these ($^{1}/_{5}$th of the total UK adult population) experiencing pain for more than one month (Dodd, 1997). The lifetime prevalence of LBP is reported to be up to 84% and after an initial episode of LBP, 44-78% suffer relapses. There is little evidence on prevalence rates in the population for chronic non-specific LBP, but it is suggested to be approximately 23% (Airaksinen et al., 2006). Apart from the personal suffering and disability incurred by people with LBP, the cost to the United Kingdom economy in 1998 was estimated to be £1,632 million per annum in direct health costs and £10,668 million in lost production and informal care (Maniadakis et al., 2000). These costs are reflected throughout the developed world.

In spite of the prevalence and consequences of LBP, and the substantial research efforts investigating its aetiology and treatment, the optimal management remains unclear (Waddell, 1999).

Clinically, I developed an interest in LBP related to static end-range postures like slump sitting. Simply teaching patients to adopt a mid-range spinal position in sitting commonly improved their pain. Similarly, I also observed that if back pain was reproduced during sit to stand or bending movements, it could be lessened or abolished by encouraging patient awareness of their low back posture during these movements. I hypothesised that if previously painful, functional static positions and dynamic movements could become pain free, local tissue sensitivity would lessen and this would potentially decrease severity and frequency of pain. By adopting these strategies, patients are able to take an active self-management role in the short- and long-term management of their condition.

Although the evidence for this was anecdotal, it was based on knowledge of spinal anatomy, pathophysiology and human movement. At this time I met Professor Mike Hurley when we both presented research at the World Congress of Physical Therapy in 1995. His research found that patients with knee pain had poor proprioceptive

acuity (accuracy of position sense) (Hurley, Scott, Rees, & Newham, 1997), which improved with exercise (Hurley & Scott, 1998b). This research on the knee and my ongoing observations of posture and movement awareness in clinical practice, encouraged me to investigate whether similar findings occurred in patients with LBP.

Before investigating whether improving patients' awareness of low back posture and movement could improve LBP outcome, research was needed to investigate whether deficits in low back position sense existed in people with LBP. Research had identified proprioceptive acuity at the knee was worse in people with knee pain, compared to those with no history of knee pain (Barrack, Skinner, & Buckley, 1989; Corrigan, Cashman, & Brady, 1992). In the few studies investigating position sense in the low back however, the results were variable, with studies commonly having methodological weaknesses such as small sample sizes (Descarreaux, Blouin, & Teasdale, 2005; O'Sullivan et al., 2003), inappropriate non-LBP (NLBP) control groups containing participants with a history of up to 3 months LBP (Newcomer, Laskowski, Yu, Larson.D.R., & An, 2000) and NLBP control subjects who could have had previous LBP provided none was present at the time of testing (Gill & Callaghan, 1998). These methodological weaknesses undermined the confidence in their conclusions.

The ability to appreciate body position and movement makes an essential contribution to control of posture and functional movement. Pain may impair this awareness and initiate or exacerbate joint damage (Hurley et al., 1997; O'Connor, Palmoski, & Brandt, 1985; Radin, Yang, Riegger, Kish, & O'Connor, 1991; Reeves, Cholewicki, Lee, & Mysliwiec, 2009). Uncertainty however, remained as to whether position sense deficits would be a consistent finding in people with LBP, suggesting further studies were required to investigate this further.

Outline of the thesis

Although acknowledged that a biopsychosocial model is critical in LBP research and clinical practice, research into all aspects of LBP (physiological, psychological and social) is important. This thesis focuses on the physiological aspect – the role of spinal position sense in the complex problem of LBP, in people with recurrent NSLBP and without LBP. The thesis has been split into the following chapters for ease of reading and to demonstrate the natural development of the research. Each study contains a summary of background literature, methods specific to the study, results, discussion including limitations and implications and summary of findings.

Chapter 1. An understanding of the sensorimotor system is required to explore the role of spinal position sense in the complex problem of LBP. The background introduces the sensorimotor system, in particular position sense, and the reasoning for investigating proprioceptive acuity in people with and without LBP.

Chapter 2 is an investigation of the stability and through range test-retest reliability of the back electrogoniometer compared to measurements using a calibrated, highly accurate, bevel protractor with known angular measures.

Chapter 3 is an investigation of position sense before-work and after work in people with recurrent NSLBP and without LBP, including test-retest reliability data.

Chapter 4 is an investigation of low back position sense in mid-range of movement from slump to extension during sitting in people with recurrent NSLBP and without LBP, including test-retest reliability data.

Chapter 5 is an investigation of where people with recurrent NSLBP and without LBP, believe a “good” sitting posture is located and also their ability to return to this position. It also investigates the relationship of their “good” sitting posture to end-range low back extension and flexion. The chapter includes test-retest reliability data.

Chapter 6. A general discussion summarising the common conclusions of the studies, the importance of the research and what it adds to the body of knowledge, implications for clinical practice, common limitations and areas for further research.

References are included at the end of the discussion.

Appendices are included at the end of the thesis.

Funding for the research

The University of Southampton funded the researcher's time to undertake a literature review that informed the background to the studies in this thesis. The research in Chapters 2 and 3 was funded by Arthritis Research UK (formerly the Arthritis Research Campaign, **arc**). The research in Chapters 4 and 5 was funded by the Private Physiotherapy Educational Foundation (PPEF).

1 BACKGROUND

1.1 Sensorimotor system

The sensorimotor system is a collective term describing the complex physiological neurosensory and neuromuscular systems and their processes (Eyre, Miller, & Ramesh, 1991; Lephart, Riemann, & Fu, 2000; Matthews, 2004). Mechanical stimuli excite peripheral mechanoreceptors in the muscles, skin, ligaments and joints. These receptors convert the mechanical stimuli to the electrical energy found in a nerve action potential causing neural signals that pass along the afferent pathway to the central nervous system (CNS) for processing (Lephart et al., 2000). The CNS integrates these signals, as well as information from the visual and vestibular receptors (Grigg, 1994; Lephart, Pincivero, Giraldo, & Fu, 1997; Snell, 2010). Here it is processed with the three motor control centres (spinal, brain stem, cerebral cortex) regulating voluntary and involuntary motor commands to co-ordinate muscle activity to control posture and movement, maintain stability (Lephart, Pincivero, & Rozzi, 1998) and reduce harmful joint loading (Sharma, 1999) (Figure 1:1).

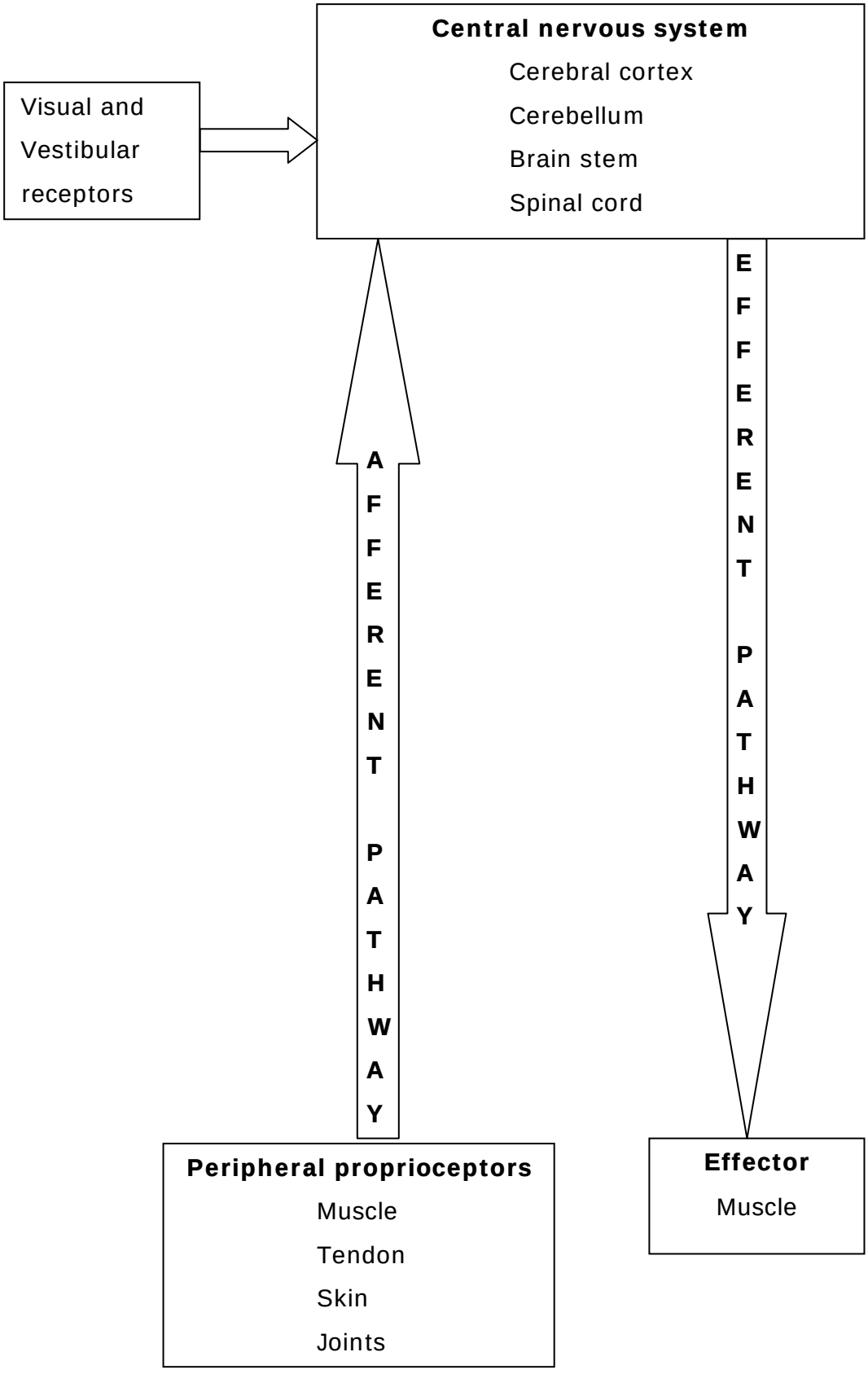


Figure 1:1. Sensorimotor system

1.1.1 Proprioception

Proprioception is the afferent (incoming) part of the sensorimotor system and relates to the senses of position and movement of body parts (Sherrington, 1907). A more detailed definition suggests it is the conscious and unconscious perception of body position, movement (Sharma, 1999), velocity, acceleration (Swinkels et al., 2000) and the force, effort, heaviness and timing associated with muscular contraction (Gandevia et al., 1992).

For the purpose of this thesis, the aspect of proprioception that is investigated is whether deficits in low back position sense (also termed position awareness in this thesis) exist in people with LBP.

1.1.2 Proprioceptive receptors

Proprioceptive receptors include muscle spindles, Golgi tendon organs, Ruffini endings, Pacinian corpuscles, Golgi tendon organ-like endings and free nerve endings (Table 1). They transmit information on joint position, skin and joint movement, and muscle tension, acting as a transducer converting a mechanical stimulus into neural impulses (Grigg, 1994; Grigg & Hoffman, 1989).

	Where located	Proprioceptive role
Muscle spindles	Muscle belly (Matthews, 1964)	• Inform CNS about muscle length or rate of change of length (Proske, 2006)
Golgi tendon organs	Tendons (Gardner, Martin, & Jessell, 2000)	• Inform CNS about tension (Proske, 2005)
Ruffini endings	Joint capsule, ligaments, menisci, skin (Boyd, 1954; Kennedy, Alexander, & Hayes, 1982) (Zimny, 1988) (Chambers, Andres, von Duering, & Iggo, 1972; Edin, 1992)	• Static joint position sense, pressure, amplitude, direction, amplitude and velocity of joint movements towards end-range (Zimny, 1988) • Maximally stimulated at extremes of range where structures are vulnerable to injury (Grigg, 1994; Zimny, 1988) • Respond to stretch of skin (Chambers et al., 1972; Edin, 1992)
Pacinian corpuscles	Deep layers of capsule, ligaments, articular fat pads, menisci (Zimny, 1988)	• Respond to mechanical pressure or compression (Grigg, 1994; Zimny, 1988) • Highly sensitive to changes in speed acting as dynamic mechanoreceptors (Boyd, 1954; Zimny, 1988)
Golgi tendon organ-like endings	Capsule, ligaments, menisci (Boyd, 1954; Kennedy et al., 1982; Schultz, Miller, Kerr, & Micheli, 1984) (Zimny, 1988)	• Active at extremes of joint range (Zimny, 1988)
Free nerve endings	Capsule, ligaments, menisci (Schultz et al., 1984; Zimny, 1988)	• Activated when joint subjected to damaging inflammatory mediators & mechanical stresses (Grigg, Schaible, & Schmidt, 1986) • Exposure to inflammatory mediators results in their increased activity, & reduced threshold to mechanical stress & joint movement (Özaktay, Cavanaugh, Blagoev, Getchell, & King, 1994; Schaible & Schmidt, 1986)

Table 1:1. Proprioceptive receptors

1.1.3 Process of sensory acquisition

The process of sensory acquisition and relative independence of different mechanoreceptors is debated (Bergenheim, Johansson, Pedersen, Öhberg, & Sjölander, 1996; Johansson, Bergenheim, Djupsjöbacka, & Sjölander, 1995), with the contribution of different receptors in relaying proprioceptive information remaining controversial. It appears likely, that populations of mechanoreceptors (an ensemble) have ranges of sensitivity and differing responses to an identical stimulus (Bergenheim et al., 1996). This enables more discrete information to be transmitted to the CNS (Erikson, 1968) and greater proprioceptive acuity.

An example is that the ability to discriminate passive muscle length is greater in a population of mechanoreceptors containing primary and secondary muscle spindles and Golgi tendon organs, compared to just containing primary muscle spindle afferents (Bergenheim et al., 1996; Johansson, Sjölander, & Sojka, 1991a).

Historically, opinions of the contribution of a particular tissue to position sense have differed. Anaesthetising the skin and finger joint results in only a partial decrease in position sense, suggesting muscles are heavily involved in proprioceptive awareness (Ferrell & Craske, 1992a; Gandevia, Hall, McCloskey, & Potter, 1983; McCloskey, Macefield, Gandevia, & Burke, 1987). Joint mechanoreceptors appear to be activated only during high loading near end of range (Grigg, 1994), and are now considered as primarily limit detectors (Proske & Gandevia, 2009).

Lengthening of a muscle increases the discharge rate of muscle spindles. Muscle spindles therefore give constant sensory feedback to the CNS about muscle length or rate of change of length (Proske, 2006). Primary muscle spindle endings may be better suited to respond to changes in muscle length and speed, contributing to both sense of

position and movement, whereas secondary muscle spindle endings are better suited to signal length changes and contribute only to position sense (Matthews, 1981; 2006; Proske et al., 2009).

Golgi tendon organs inform the CNS about tension (Proske, 2005). When muscle tension suddenly increases, the Golgi tendon organs respond dynamically, sending signals to the spinal cord, stimulating an inhibitory reflex. This negative feedback mechanism prevents excessive tension developing in the muscle (Biedert, 2000).

Studies on the finger have demonstrated that the skin enhances proprioceptive input from muscle and joint afferents (Ferrell et al., 1992a; Ferrell & Milne, 1989). Studies of the skin of the hand (Edin, 1992; Edin & Johansson, 1995), elbow and knee (Collins, Refshauge, Todd, & Gandevia, 2005), suggest stretch receptors in the skin also provide direct proprioceptive information about joint position to the CNS. It is now widely accepted that skin has a major direct role in position sense in some areas of the body (Proske et al., 2009), although it is yet to be determined whether the skin over the low back acts similarly.

Thus, muscle and tendon mechanoreceptors are currently considered the primary structures responsible for providing position sense through range, although the muscle spindles are themselves significantly influenced by information provided by joint afferents (Johansson, Sjölander, & Sojka, 1990), and the skin (Matthews, 1981). How the CNS distinguishes between afferent information from muscle spindles on muscle length changes and their motor activity, remains to be determined (Proske, 2006).

In addition, the sense of effort is believed to contribute to position sense (Proske et al., 2009). Studies have shown that when the afferent and efferent supply below the elbow is blocked and participants try to move their anaesthetised and paralysed hand, they can perceive their hand position to be up to 20 degrees displaced (Gandevia, Smith,

Crawford, Proske, & Taylor, 2006). The motor command or effort signals produce an illusion of the wrist moving even when it has not moved, with greatest error associated with greater effort. This appears to be associated with a copy of the efferent information, received by the anterior motor neurons, being transmitted back to the cerebellum via the ventral spinocerebellar tracts (Hall, 2010).

How the mix of afferent information from the periphery and central signals like these, are combined to give awareness of position in normal movement, is still to be understood (Proske, 2006; Proske et al., 2009). In addition, the human studies to date have concentrated on the limbs and it is unknown whether similar findings would occur in the low back.

1.1.4 Afferent pathways

Proprioceptive information is relayed to the CNS at high speed (up to 120m/sec for Type Ia, Aα fibres) whereas nocioception (pain) is relayed at lower speed (up to 30m/sec for Type III, Aδ fibres and up to 2m/sec for Type IV, C fibres) (Snell, 2010; Strandring, 2008). The afferent pathways includes the proprioceptive receptor and its afferent nerve fibre, the synapses within the CNS terminating on alpha motor neurons or interneurons, and the nerve fibres forming the afferent tracts in the spinal cord. These afferent tracts (e.g. the dorsal and ventral spinocerebellar, and medial lemniscus tracts) convey afferent information, including proprioceptive, for interpretation and processing in supraspinal levels (Lephart et al., 2000; Snell, 2010).

1.1.5 Sensorimotor processing

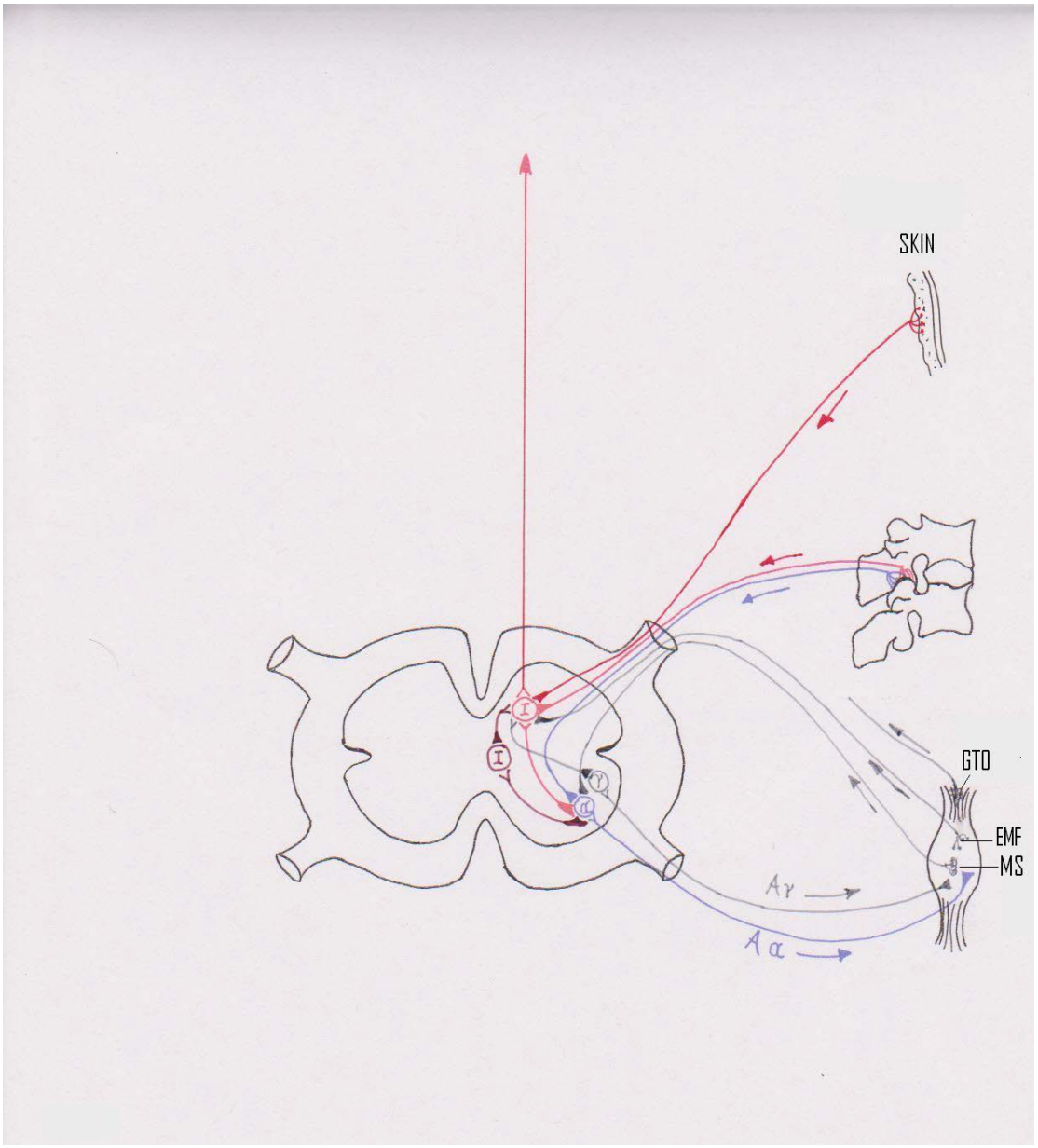
Proprioceptive information from afferent receptors is transferred to the three motor control centres (spinal; brain stem; cerebral cortex) and related motor areas (cerebellum; basal ganglia) via these afferent pathways (Lephart et al., 2000). The motor control centres are responsible for decoding and processing proprioceptive information

(Ghez & Krakauer, 2000). Although not directly involved in controlling motor neuron activity, the related areas are crucial in modulating and regulating the motor commands originating in the motor control centres (Lephart et al., 2000).

Sensorimotor processing at spinal level includes monosynaptic and complex polysynaptic spinal reflex reflexes that allow unconscious processing of afferent proprioceptive information, resulting in reflex muscle activation (Lephart et al., 2000). Muscle and tendon mechanoreceptors are considered the primary structures responsible for mediating reflex activity, although muscle spindles are themselves significantly influenced by skin (in particular) and joint afferent information (Johansson et al., 1990; Proske et al., 2009). Interneurones link afferent pathways to anterior motor neurons (Appleberg, Hulliger, Johansson, & Sojka, 1979) or ascending tract cells, transmitting signals to higher levels (brain stem, cerebral cortex), allowing conscious awareness of propriocpetive information (Figure 1:2).

In addition, sensorimotor processing at spinal level includes sending back information – efferent copy - via the ventral spinocerebellar tracts, on the sequence of motor signals arriving at the anterior motor neurons from higher centres (Dye, 2000; Proske, 2006). This allows for feedback control of these motor signals (Biedert, 2000; Dye, 2000; Proske, 2006) (Figure 1:3).

In general, the spinal cord controls simple reflex motor responses, the lower parts of the brain control complex responses and the cerebral cortex controls the most complex responses (Hall, 2010; Lephart et al., 1997). Figure 1:4 gives an overview of the different roles of the motor control centres and related motor areas.



Key

γ = gamma motorneuron

Aγ = A gamma

GTO = Golgi tendon organ

EMF = extrafusal muscle fibres

MS = muscle spindle

Figure 1:2. The interaction of muscle, tendon, skin and joint afferents mediating reflex activity and transmission to higher levels

Based on Snell (2010), Strandring (2008) and Biedert (2000)

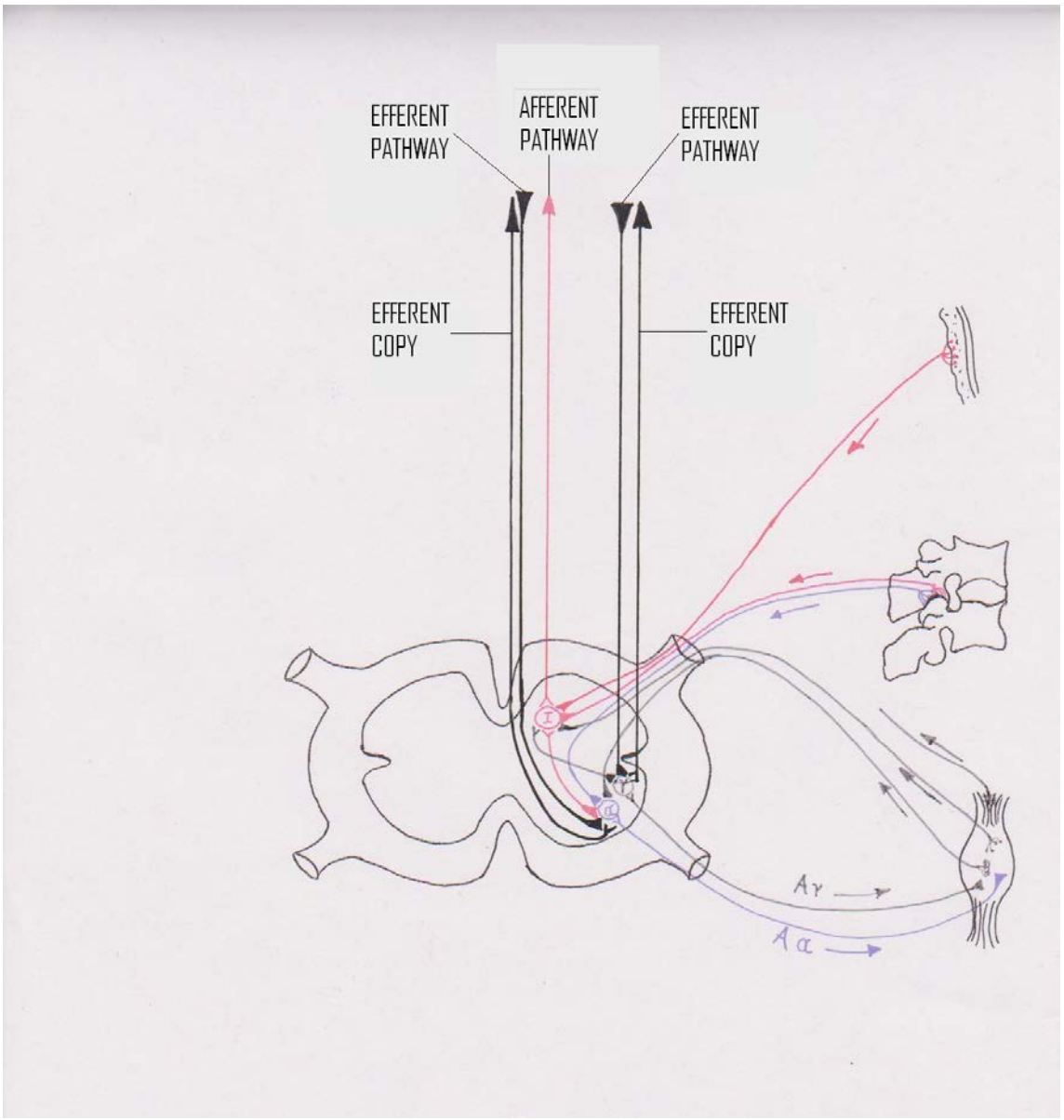


Figure 1:3. Sensorimotor function at spinal cord level and efferent pathways, including efferent copy sent back to higher levels
Based on Snell (2010), Strandring (2008) and Biedert (2000)

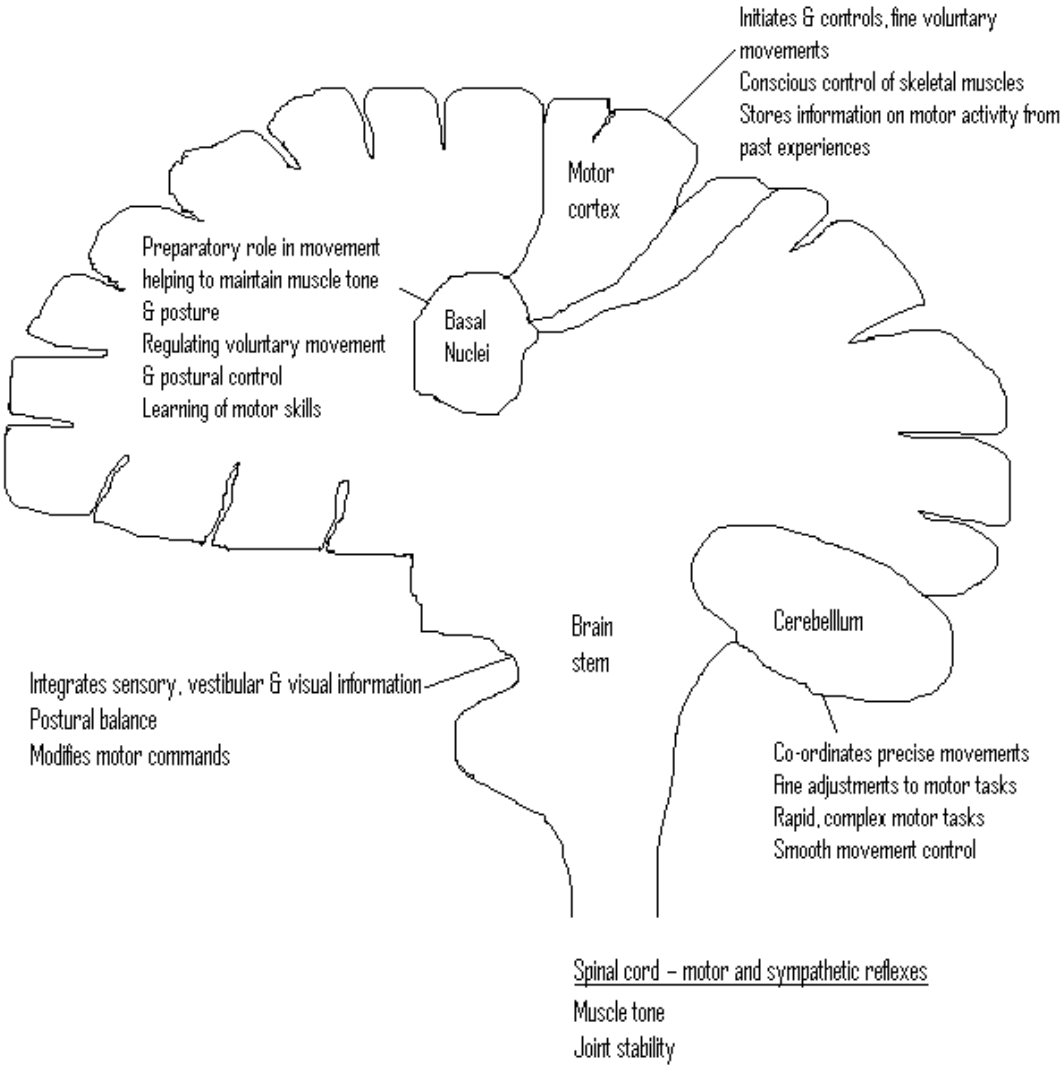


Figure 1:4. Overview of motor control in the central nervous system
Based on content from Snell (2010) and Biedert (2000)

The *somatosensory cortex* is responsible for providing conscious awareness of joint position sense and movement sense (Lephart et al., 2000). The sensory homunculus (Figure 1:5), is a representation of the somatosensory cortex, which maps to specific areas of the body, depending on the importance of afferent input from that area (Snell, 2010). A large area of the cortex receives sensory information from the hand and lips, but only a small area is devoted to the back. The area devoted to the back is also much smaller than the area devoted to the limbs. Consequently, the conscious awareness of position sense in the back in all people, regardless of whether or not they experience LBP, may be less in the trunk in comparison to the limbs. The results of position sense testing in the trunk may therefore be poorer than in the limbs, with or without the presence of LBP.

Accuracy of position sense will depend on whether the map representing the surface of the back is intact (Luomajoki & Moseley, 2010). It is however reported, that in LBP the cortical map of the low back is enlarged and shifted 2.5cm medially (Flor, Braun, Elbert, & Birbaumer, 1997). The consequences for position sense remain unknown.

The *primary motor cortex* controls fine voluntary movements and consciously controlled movements of skeletal muscles (Biedert, 2000). The motor homunculus (Figure 1:6), maps to specific areas of the body depending on the importance of efferent input to that area. The cortical area responsible for a movement is proportional to the amount of skill required during movement (Snell, 2010). The area devoted to the back is again, much smaller than the area devoted to the limbs. This suggests that less importance is given to cortical control of fine voluntary movements and consciously controlled movements of skeletal muscles in the low back. Consequently, the conscious awareness and ability to reposition the low back in all people, regardless of whether or not they experience LBP, may be less in the trunk in comparison to the limbs.

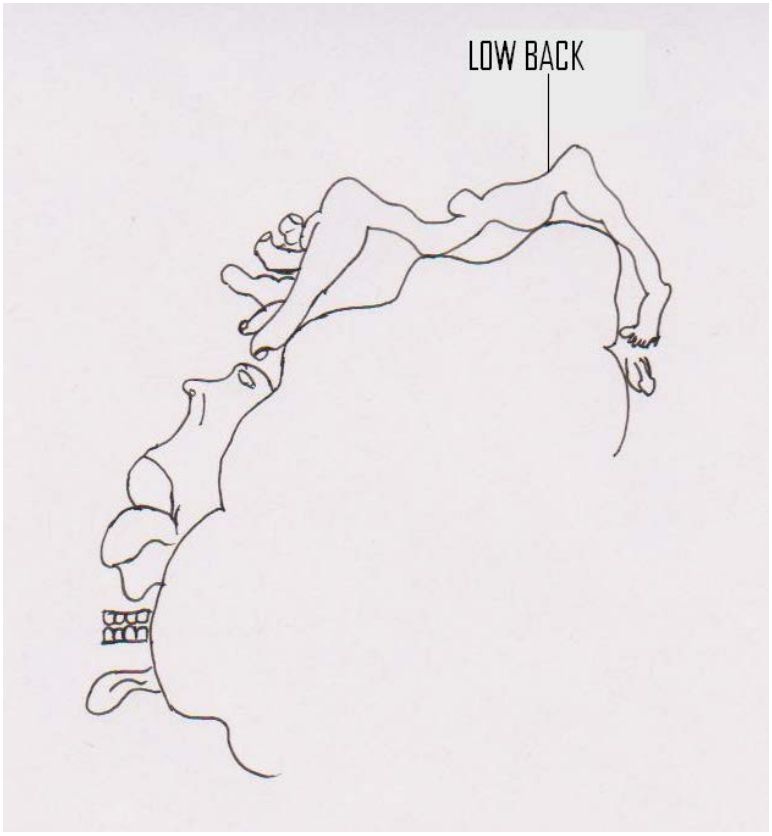


Figure 1:5. The sensory homunculus – modified from (Butler & Moseley, 2003)

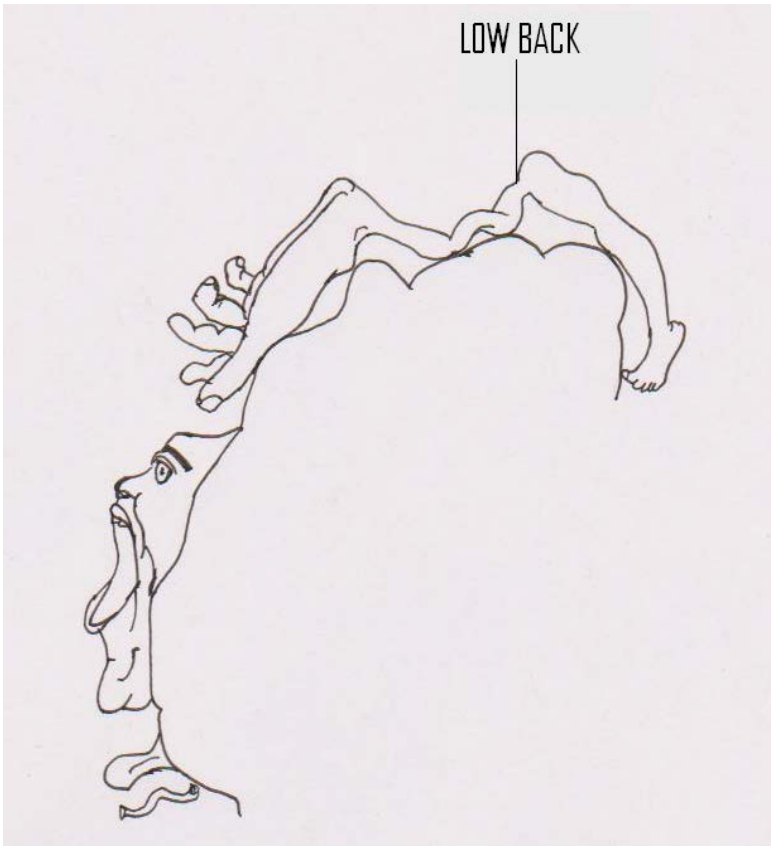


Figure 1:6. The motor homunculus – modified from (Snell, 1980)

The motor cortex receives proprioceptive information directly from the periphery, and indirectly from the somatosensory cortex, related motor areas, the cerebellum and basal ganglia (Krakauer & Ghez, 2000; Naito, 2004; Romo & Salinas, 2003). It initiates and controls, complex and fine voluntary movements via the corticospinal tracts, working closely with the lower brain. The corticospinal neurons within the cerebral motor cortex are able to manage intricate patterns of muscle activity, through control of spinal reflexes at spinal cord level (Biedert, 2000).

It appears that neurons in the motor cortex are able to respond to load during both posture and movement, and can rapidly switch their response to loads and movement, during a change from control of posture to movement, or vice-versa (Scott, 2008). This may suggest there are complex, but specialised neural control processes, one for posture and another for movement (Kurtzer, Herter, & Scott, 2005). The significance for testing position sense is that with different central processing, if deficits in position sense of the trunk are found, it does not mean deficits in movement sense will be found, and vice versa.

1.1.6 Efferent pathways

Efferent (outgoing) pathways are formed by neurons travelling from the CNS to the effector – the motor endplate in muscle. The pathways include the initiation level in the CNS (cerebral cortex; brain stem; spinal), nerve fibres forming the efferent tracts leading to the ventral roots and motor neurons (alpha and gamma) including interneurons, and ending on the motor endplates (Lephart et al., 2000; Snell, 2010).

The efferent tracts are a bundle of nerve fibres found in the spinal cord carrying descending information from supraspinal structures to neural networks in the spinal cord. An example is the corticospinal tract that carries motor information from the cortex to interneurons in the intermediate regions of the grey matter of the spinal cord (Lephart et al., 2000; Snell, 2010).

1.1.7 Motor function at spinal level

The grey matter contains interneurons, and anterior motor neurons made up of alpha and gamma motor neurons (Hall, 2010). The *alpha motor neurons* transmit impulses to large skeletal muscles fibres via A alpha (Aα) nerve fibres. The muscle fibres innervated by one nerve fibre is termed a motor unit. Large muscles can have hundreds of muscle fibres in a motor unit for gross control and smaller muscles have very few muscle fibres in a motor unit for fine control (Biedert, 2000). The *gamma motor neurons* transmit impulses to the small and specialised intrafusal fibres in the muscle spindles via the A gamma (Aγ) nerve fibres (Biedert, 2000). There are two types of gamma motor neurons 1) gamma-s controlling static sensitivity of muscle spindles, and; 2) gamma-d controlling dynamic sensitivity of muscle spindles (Johansson, 1991).

These gamma motor neurons receive constant information from peripheral mechanoreceptors and are also constantly influenced by the motor neurons of descending pathways (Johansson, Pedersen, Bergenheim, & Djupsjöbacka, 2000). This mechanism allows the CNS to directly influence muscle activation and its relative stiffness as described below.

1.1.8 Muscle stiffness

A muscle develops tension when stretched. Passive muscle stiffness is a product of the relationship of muscle length and tension (Johansson et al., 2000; Johansson & Sojka, 1991b). Total muscle stiffness is therefore a permutation of 1) its intrinsic passive structure and properties, and 2) its reflex-mediated activity (Akazawa, Aldridge, Steeves, & Stein, 1982; Akazawa, Milner, & Stein, 1983). The passive stiffness is thought to be related to the presence of cross-bridges between actin and myosin, within the sarcomeres of muscle fibres (Ford, Huxley, & Simmons, 1981; Proske & Morgan, 1999).

The reflex-mediated stiffness of a muscle is a response to excitability of the alpha motorneuron pool and stretch evoked activity in muscle spindle afferents (Johansson et al., 2000; Johansson et al., 1991b). Therefore, fusimotor control (fusimotor system = muscle spindles and their efferent gamma motor neurons) of muscle spindle sensitivity will also influence muscle stiffness (Akazawa et al., 1983). This reflex-mediated activity although variable, is believed to increase muscle stiffness by 40% to 100% when investigating the stiffness response to stretch at differing levels of voluntary muscle contraction (Sinkjaer, Toft, Andreassen, & Hornemann, 1988). This was reported however, in the muscles of the ankle. Whether this occurs similarly in all muscles and notably the lower trunk muscles, remains unknown. It has been subsequently suggested, that as much as 50% of total muscle stiffness during contraction, is caused by the stretch reflex (Toft, Sinkjaer, Andreassen, & Larsen, 1991). Thus, the proprioceptive receptors influence muscle stiffness through their reflex activation of the muscle spindle system (Johansson, 1991; Johansson et al., 1991a). This muscle stiffness is an important function, as it assists in protecting joint structures against potentially harmful movements.

To create further stiffness in muscle, signals from the motor cortex will commonly coactivate both the alpha and gamma motor neurons, causing simultaneous contraction of extrafusal and intrafusual muscle fibres (Johansson et al., 2000).

The implication of muscle stiffness to position sense is that afferent information from muscle spindles may vary depending on the amount of stiffness in a muscle. This could lead to alterations in position sense. Whether position sense in the low back is enhanced or decreased when there is too much trunk muscle stiffness, is not fully understood.

A further property of muscle that will influence the amount of tension and stiffness found within it, is its thixotropic behaviour. Passive muscle will lie taught (i.e. show a degree of stiffness) if it is held stretched and slack if held short. In a slack muscle, there is reduced strain on spindle sensory endings, thus the resting discharge rate of

muscle spindles will be low (Proske, Morgan, & Gregory, 1993). When taught, there is increased sensitivity of muscle spindles and a full muscle response including peak tension, will be reached more rapidly (Morgan, Prochazka, & Proske, 1984; Proske, 2006).

In its working range however, a passive muscle can be taught or slack depending on the immediate history of its length and contraction (Proske et al., 1999), i.e. was it previously contracted isometrically, contracted and then stretched, or contracted and then shortened. This creates uncertainty about the tension response of a muscle at the beginning of a subsequent movement (Proske et al., 1993). Timing of subsequent muscle contractions will vary, depending on this immediate history of contraction, as will its reflex action and also its afferent feedback on position sense through the muscle spindle system (Proske et al., 1999).

Although initial lengthening of a muscle results in increased firing of muscle spindles, prolonged lengthening in the paraspinal muscles of cats (2 to 8 seconds) followed by a return to a more neutral position, has been shown to decrease muscle spindle sensitivity to position, movement and velocity (Cao & Pickar, 2011; Ge, Long, & Pickar, 2005; Ge & Pickar, 2008). If a similar response occurred in humans at the neutral position of the spine, where there are already low levels of muscle activity (Cholewicki & McGill, 1996), following prolonged slump sitting, this decrease in muscle spindle sensitivity at a mid-range spinal position may increase the vulnerability of the spine to unexpected vertebral movements and loads.

The relevance to position sense testing is that the property of a muscle, such as activity of its muscle spindles, and therefore its ability to sense positions, will vary depending on the previous immediate history of its length and contraction (Proske et al., 2009). Different start position adopted in position sense testing of the low back for example and different activity levels of a muscle prior to position sense testing, could therefore lead to different position sense responses, regardless of the presence of LBP or not.

1.1.9 Motor control mechanisms

Proprioceptive information is believed to update motor programmes to improve motor output. This important role is supported by the knowledge that in people with severe proprioceptive deficits due to large fibre afferent neuropathy, there is difficulty in acquiring new motor skills due to a lack of awareness of limb position and subsequent decrease in necessary planning and control of movement (Gordon, Ghilardi, & Ghez, 1995).

Proprioceptive information from the periphery influences motor control by either feedback (reflexive/reactive) or feed-forward (preparatory/anticipatory) mechanisms (Lephart et al., 2000; Ting et al., 2009).

Feedback mechanisms involve a reactive spinal level reflex in response to movement and articular loads. The process however, involves many reflex pathways and as the activation of muscles occurs reactively, it consequently involves a time delay of up to 500 milliseconds (Ting et al., 2009). This suggests that it may be important in maintaining the position of our limbs / trunk or the forces applied to objects when held (Ghez et al., 2000).

Feed-forward mechanisms involve pre-activation of muscles in anticipation of a task or load. This provides initial stability while the delayed feedback response is awaited (Ting et al., 2009). It involves on-going proprioceptive information being integrated with past experiences of movements and/or tasks, resulting in pre-activation of muscles to help control posture and movement. It is particularly important for rapid action and it helps to modify the reactive feedback response at spinal level (Ghez et al., 2000).

These two motor control mechanisms are interdependent, occurring simultaneously in motor activation (Ting et al., 2009). In the trunk, there is evidence for feed-forward co-activation and therefore, stiffening of the spine, in anticipation of postural movement e.g. due to

arm movement (Allison, Morris, & Lay, 2008b; Hodges & Richardson, 1997). There is also evidence for the importance of feedback mechanisms for control of posture when sitting (Willigenburg, Kingma, & van Dieën, 2010). Due to their high sensitivity to small stimuli, proprioceptive input to the CNS from muscle spindles plays an important role in motor contol (Burgess, Wei, Clark, & Simon, 1982; Matthews, 1982) and the feedback control of posture (Matthews, 1981). The exact contribution of feedback or feed-forward mechanisms and their interaction in the CNS, muscles and joints, is yet to be fully understood.

Any deficiencies in low back position sense found during testing, would therefore affect both feedback motor control mechanisms in response to movement and load, and feed-forward motor control in anticipation of a movement or load. People with position sense deficits would consequently be more vulnerable to injury and LBP.

1.1.10 Summary of implications for position sense testing

The previous section (1.1) provides a brief overview of the sensorimotor system in general, to facilitate understanding of possible influence of the peripheral/spinal mechanisms and the brain, with reference to position sense and LBP. It highlights the importance of the the whole sensorimotor system from peripheral receptors to the CNS (at both spinal and higher levels) and back to the periphery. The high speed at which information on position sense is relayed to the CNS, suggests importance. Position sense testing however, should not just be considered as a test of peripheral or peripheral-spinal mechanisms, as by its nature testing position sense requires conscious awareness at higher levels.

The level of importance for both sensory information and motor output, which is given to position sense at higher levels, is variable depending on the part of the body involved. Position awareness and any motor

response would appear to be greater when involving for example the hand, lips and feet, but less for the back. Consequently, the conscious awareness of position sense and ability to reposition the low back in all people, regardless of LBP, may be less in the trunk compared to the limbs.

The different central processing of posture and movement suggests that variability in the results of position sense and movement sense may exist. Proprioceptive deficits in one of these may therefore be found in the low back, but not necessarily deficits in both position and movement sense of the low back.

When testing position sense, consideration needs to be given to the possible effect of muscle stiffness to position sense. In addition, muscle spindle sensitivity and thus ability to sense position, will vary depending on the previous immediate history of a muscles length and contraction (Proske et al., 2009). Consequently, in interpreting studies that investigate position sense, consideration needs to be given to the start position and muscle activity levels prior to testing, as this can lead to different position sense responses.

Many of the neurophysiological studies investigating the function of the sensorimotor system have been performed on small numbers of anesthetised or decerebrate animals. This lessens or excludes the influence of the brain and direct transfer of findings from animals to humans, may or may not be appropriate. It is acknowledged that similar studies in human models are often impossible on ethical grounds and animal studies are widely used to develop an understanding of potential mechanisms in man. It is vital however, to investigate clinical pain or induced pain in humans to fully understand pain mechanisms in man. An opportunity to more easily observe the human brain now exists (Matthews, 2004), by using functional magnetic resonance imaging (fMRI) and transcranial magnetic stimulation (TMS) (Moseley, 2008b; Strutton, Catley, McGregor, & Davey, 2003; Strutton, Theodorou, Catley, McGregor, & Davey, 2005;

Tsao, Galea, & Hodges, 2008a) to improve our understanding of the location of neuronal activity and electroencephalography (EEG) to inform when this activity occurs (Moseley, 2008b).

The brain provides an area of future research to fully understand the mechanisms involved when testing position sense (Matthews, 2004; Moseley, 2008b). Whether differences both in location of brain activity and when activity occurs, can be found between people with and without LBP when testing position sense in the trunk, is a potential area for development of the research contained in this thesis.

1.2 Sensorimotor system and LBP

Sensory information from muscle, skin and joint receptors in the low back, as well as from the vestibular and visual systems, is relayed to the CNS where it is processed (Matthews, 2004). The motor control centres then co-ordinate appropriate trunk muscle activity to control movement and posture (Lephart et al., 1998), reduce harmful joint loading (Sharma, 1999), and therefore minimise the potential for LBP.

The proprioceptive receptors and afferent pathways thus contribute to the CNS selecting the appropriate co-ordinated muscle recruitment required to perform complex functional tasks. As a consequence, if position sense is impaired, for example due to ligament injury, this could adversely affect motor control and co-ordination of muscle activity during every day movements (Kålund, Sinkjaer, Arendt-Nielsen, & Simonsen, 1990). This can affect joint control and stiffness causing abnormal loading and excessive harmful range of movement (O'Connor et al., 1985; Radin et al., 1991). This predisposes the spine to possible injury and pain (Panjabi, 2006), re-injury and acceleration of degenerative changes in people with LBP (O'Connor et al., 1985; Reeves et al., 2009).

1.2.1 Pain and its effect on position sense

Accurate position awareness and controlled movement are vital for the health and normal functioning spinal joints. Abnormal mechanics of the spine may occur due to injury or degenerative changes including internal disc disruption, facet osteoarthrosis and infection (discitis) (Bogduk, 1997). Injury to articular and muscular tissue causes dysfunction of mechanoreceptors resulting in partial deafferentation and decreased proprioceptive information to the CNS (Lephart et al., 2000). The onset of any pain may be via inflammation, biochemical and structural changes in the disc, changes in neural tissue, nutritional and biochemical changes in joint structures (Bogduk, 1997; Raja, Meyer, & Campbell, 1988).

An acutely damaged joint with acute inflammation will increase the sensitivity of afferent fibres including nociceptors in structures like the capsule, both at rest and during movement. This may subsequently increase the afferent information on position and movement sense sent to the CNS. In response, motor reflexes at spinal level are likely to occur in an attempt to limit any excessive movement to protect the joint from further damage (Schaible & Schmidt, 1985). Additionally, in chronic joint conditions a decrease height of joint space could increase movement stresses at the joint capsule and ligamentous structures (e.g. varus and valgus stresses at the knee), further altering proprioceptive afferent information (Attfield, Wilton, Pratt, & Sambatakakis, 1996).

With injury and pain, afferent information is therefore corrupted, resulting in delay and/or disruption of normal muscle response patterns. As spinal ligaments have an important sensory function in control of joint position sense, injuries to these ligaments are likely to cause disturbance of spinal position sense (Sjölander, Johansson, & Djupsjöbacka, 2002) and postural awareness in the trunk (van Dieën, Selen, & Cholewicki, 2003b). Injury to the annulus fibrosus, which is richly innervated with mechanoreceptors (Roberts, Eisenstein, Menage,

Evans, & Ashton, 1995), is also likely to have a similar affect on joint position sense and postural awareness (van Dieën et al., 2003b). These effects are likely to be caused by corrupted afferent information affecting the motor response.

Inappropriate sensory information from mechanoreceptors alters the motor response of the CNS, adversely affecting neuromuscular protective mechanisms (reflexes generated by muscle, cutaneous and articular proprioceptors) that control muscle activity, joint stiffness and protect joints from abnormal loading and excessive harmful range of movement (O'Connor et al., 1985; Radin et al., 1991). In the knee for example, co-activation of the quadriceps and hamstrings occurs during many functional movements and results in equal load distribution over the articular surface (Baratta et al., 1988). This co-activation emphasises how important muscle coordination is for functional joint control and for protecting articular surfaces from abnormal loading. As generation of an inappropriate motor response will adversely affect coordinated muscle activity, it may therefore lead to increased, poorly distributed, articular loading, pain and damage. Over time this can result in degenerative joint changes, which further destroy or disturb the proprioceptive nerve endings in the joint complex, muscles and tendons (Hurley et al., 1997).

To date, it has not been determined whether proprioceptive impairment precedes articular damage, or is a consequence of articular damage (Sharma, 1999) or both. However, it is believed alterations in neuromuscular control adversely affect joint stiffness and control of movement. This alters patterns of movement and contributes to repetitive injuries resulting in progressive damage to the joint (O'Connor et al., 1985; Reeves et al., 2009).

Consequently, injury and pain in the low back can corrupt the proprioceptive information sent to the CNS, altering the motor response. This may therefore lead to differences in position sense when comparing people with and without LBP.

1.2.2 Role of muscle in the aetiology and management of LBP

Until the early 1990's, mechanical changes of spinal articular structures (i.e. bones, articular surfaces, intervertebral discs, ligaments, nerves etc) were the main focus of research (Bogduk, 1997). The role of muscles in the aetiology and management of LBP have received much less research attention, although the importance of muscles in maintaining "good spinal posture" during activities of daily living (e.g. sitting, standing, lifting etc) - a strategy advocated as being effective in reducing LBP - is now better appreciated (Cholewicki et al., 1996).

1.2.2.1 Trunk muscle activation

Alterations in the nervous system control of the lumbar trunk muscles have been shown in people with chronic LBP (Radebold, Cholewicki, Polzhofer, & Greene, 2001; Sihvonen, Partanen, Hänninen, & Soimakallio, 1991; van Dieën, Cholewicki, & Radebold, 2003a), including those with sciatica due to disc herniation (Leinonen et al., 2001). These alterations will affect sensorimotor function including postural control, position sense and movement awareness.

It has been reported in studies involving people with chronic LBP (Hodges & Richardson, 1996) or in healthy people with experimentally induced LBP, that activation of the deepest abdominal muscle, transversus abdominis (TrA), is altered (Hodges, 1999; Hodges, Moseley, Gabrielsson, & Gandevia, 2003). Delayed activation of the TrA muscle to upper limb (Hodges et al., 1996) and lower limb movements (Hodges & Richardson, 1998) was identified in these small scale studies with 15 people with recurrent LBP (mean of 10 +/- 9 episodes per year; mean duration of symptoms 9 +/- 8 years) and 15 people without LBP. As these studies have small numbers of participants, there remains a need to ensure consistency of results among larger populations of people with LBP.

It is believed this muscle's postural activation contributes to vertebral stiffness (Hodges, Cresswell, Daggfeldt, & Thorstensson, 2001), but in

people with chronic pain, its normal control is altered, even during remission from back pain (Hodges, 2001; MacDonald, Moseley, & Hodges, 2009). These delays in muscle responses could affect people's ability to make appropriate responses to normal or abnormal loading during static and dynamic postures, suggesting decreased or delayed awareness of spinal posture and movement may be found. This can lead to changes in static and dynamic joint loading, thereby contributing to recurrent LBP (Hodges, van den Hoorn, Dawson, & Cholewicki, 2009).

The studies suggested that bilateral activation of the deep trunk muscle - TrA - is delayed in people with LBP during single rapid arm movements (Hodges, 1999). It was reported that the activation of TrA was not dependent on the direction of arm movement and it was subsequently implied, that the muscle had an important trunk stabilising role, during all upper limb functional movements (Hodges et al., 1997). Any delay in the activity of muscles e.g. TrA, with a high density of muscle spindles (Amonoo-Kuofi, 1983; Kokkorogiannis, 2004), that inform the CNS on position awareness, could lead to alterations and possible deficits in position sense in people with LBP.

Other studies using fine-wire EMG, found anticipatory activation of TrA occurred, significantly earlier for shoulder flexion than abduction and extension (Mannion et al., 2008). This suggests that anticipatory activation is direction-dependent, a finding consistent with a primary role in anticipatory postural adjustments, rather than trunk stability. To have a unique stabilising role for the spine, bilateral activation of TrA would be required prior to limb movements. Contralateral activation has been found however, in healthy individuals with no LBP, during arm movements. This single sided response of TrA to arm movement is consistent with a role in anticipatory postural adjustments rather than a unique spinal stability role (Allison & Morris, 2008a; Allison et al., 2008b). Whether transversus abdominis can enhance stability on its own is also questionanble (Grenier & McGill, 2007). Its role in anticipatory postural adjustments that relies on important

proprioceptive information including position sense of the low back is less controversial (Allison et al., 2008a; Allison et al., 2008b).

Recently, in a large sample of people with LBP (48 people with chronic NSLBP; 48 without LBP), ultrasound tissue Doppler-imaging found no delay in TrA feed-forward activation during arm movements, although 26% of all data was ignored due to methodological difficulties e.g. poor ultrasound or EMG quality (Gubler et al., 2010). Their findings contradict Hodges (1999 and 2001), and activation of the lateral abdominal muscles even occurred slightly earlier in people with LBP. This is consistent with anticipatory postural adjustments and protective adaptation, to avoid further pain and injury.

It is possible that intramuscular electrodes alter the activity of deep trunk muscles in people with LBP (MacDonald et al., 2009), resulting in delayed activation, although it is suggested they do not (Jacobson, Gabel, & Brand, 1995). When people without pain perform single arm movements, there is delayed activity of the deep trunk muscles when under stress i.e. participants were told they were not performing well in a simple colour-word test regardless of their performance (Moseley, Nicholas, & Hodges, 2004b). Studies using needle electrodes have endeavoured to minimise any stress associated with the use of EMG (MacDonald et al., 2009), to lessen the likelihood of the recordings been influenced by the procedure itself, rather than a true reflection of the activity of a muscle during everyday non-stressful tasks.

Studies rarely comment on the level of stress and its influence on muscle activity during a testing procedure. In experimental situations where stress would not influence findings however, such as in biomechanical modelling, it is suggested that decreased activation of the deep trunk muscles may decrease fine, segmental control of the spine (Wilke, Wolf, Claes, Arand, & Wiesend, 1995). This lack of fine, segmental control, will subsequently lead to less feedback on postural awareness.

There is evidence that delayed activity in the deep lumbar multifidus occurs in 15 people with recurrent unilateral LBP compared to 19

people with no LBP, when using intramuscular electrodes, even when in remission from their back pain. This delay was greatest on the previously painful side (MacDonald et al., 2009).

There is a lack of consistency in the findings of different studies, suggesting variable trunk muscle activation occurs in people with LBP. The deep trunk muscles have an important role in position sense and if delayed anticipatory activation of the deep trunk muscles occurs in people with LBP, this could affect their low back position sense. Any alteration in trunk muscle function could alter the sensory feedback informing position sense or the motor output response. This could lead to possible alterations in acuity of low back position awareness in people with LBP. If trunk muscle activity is not consistently affected by LBP, it is possible that no differences in position sense will be found. Similarities in muscle activity levels, muscle spindle sensitivity and afferent information informing the CNS on position sense, may explain why many studies have reported no difference in position sense between people with and without LBP (Descarreaux et al., 2005; Lam, Jull, & Treleaven, 1999; Newcomer et al., 2000).

1.2.2.2 Trunk muscle wasting

The important role of muscle in LBP has been demonstrated in a study of 26 patients with acute LBP, where it was shown that multifidus wasting (reduced cross-sectional area) occurs on the side of LBP – the mean duration of LBP was 12.1 days (SD 13.9) for men and 14.6 days (SD 16.6) for women (Hides, Stokes, Saide, Jull, & Cooper, 1994). A further study involving 39 patients with acute LBP, found the muscle wasting does not spontaneously recover even with resolution of symptoms (Hides, Richardson, & Jull, 1996). Interestingly, there was no reported correlation between the amount of wasting and severity of symptoms. An animal study, has also demonstrated rapid segmental atrophy of lumbar multifidus after experimental disc injury (Hodges, Holm, Hansson, & Holm, 2006).

The deep back muscles, particularly multifidus, are crucial for normal segmental control in the low back (Wilke et al., 1995). Resultant dysfunction and decreased sensitivity in the muscle spindles within multifidus, would decrease proprioceptive acuity and affect control of segmental stiffness and movement (Brumagne, Lysens, Swinnen, & Verschueren, 1999b).

Management strategies have been effective in addressing these problems in the deep trunk muscles and in reducing LBP. This has been demonstrated in 21 patients with acute LBP (Hides et al., 1996) and 22 patients with chronic LBP who had a diagnosis of spondylolisthesis (O'Sullivan, Twomey, & Allison, 1997b). Their success is likely to be because the lumbar trunk muscles contribute to control of spinal position and movement of the low back (Cholewicki et al., 1996; Wilke et al., 1995), and improvements in these can reduce LBP. Little research attention has been directed however, at investigating the sensory (proprioceptive) role of trunk muscles in the protection and normal functioning of vertebral joints, and possible changes due to LBP.

1.2.2.3 Muscle spindles and LBP

Muscle spindles play a vital role in proprioception and motor contol (Burgess et al., 1982; Matthews, 1982). They have a high sensitivity to small stimuli, so even the slightest muscle stretch leads to a substantial afferent signal being sent to the CNS. This enhances the ability of the muscle spindle to be involved in the feedback control of posture (Matthews, 1981).

Muscle spindles and vibration

The importance of muscle spindles in proprioceptive acuity has been shown in studies investigating the effect of vibration in the limbs (Cordo, Gurfinkel, Bevan, & Kerr, 1995; Goodwin, McCloskey, & Matthews, 1972; Roll & Vedel, 1982) and in the low back during sitting (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; Brumagne et al., 1999b). In people with NLBP, vibration of multifidus which is densely populated with muscle spindles (Amonoo-Kuofi, 1983), alters

their afferent input to the CNS inducing an illusionary lengthening of muscle whilst the vibration is applied. This illusion appears to be due to vibration causing false messages to be sent from muscle spindles to the conscious level. The cortex interprets these false messages as signalling muscle stretch, creating an illusion of joint movement (Goodwin et al., 1972).

In the studies involving vibration of multifidus, 16 participants without LBP (Brumagne et al., 1999b) and 21 without LBP (Brumagne et al., 2000), starting from an anterior tilt position, believed their sacrum/pelvis was more posteriorly tilted than it actually was during application of vibration and they undershot their target positions. This corresponded with them reproducing a more anteriorly tilted sacrum/pelvis than the target position (Brumagne et al., 2000; Brumagne et al., 1999b). Paradoxically, in 23 people defined only as having a history of "mechanical" low back pain, vibration improves proprioceptive acuity during its application, by possibly inducing a shortening illusion in muscle length (Brumagne et al., 2000). In these low back studies, the mean age of participants was early 20's, so uncertainty exists about findings in other age groups.

What these studies suggest is the important role of muscle spindles in position sense of the low back. There appears to be alterations in sensitivity to vibration in the brain and/or locally in the muscle spindle due to pain. It would appear that pain may heighten sensitivity to vibration. The exact mechanism of vibration effects at spinal level and in higher centres, and the reasons for opposite effects in people with and without LBP, remains unclear. Vibration studies have confirmed the importance of muscle spindles in proprioceptive acuity, although more recent studies using vibration report the role of other proprioceptive afferents from muscle, skin and joint should not be underestimated (Cordo, Gurfinkel, Brumagne, & Flores-Viera, 2005).

Muscle spindles, muscle stiffness and LBP

Muscle spindles also have a vital role in muscle stiffness and their over-activity can lead to muscle pain in the low back. Heightened muscle stiffness can result in production and release of substances such as arachidonic acid, histamine and lactic acid, which can cause muscle pain. These substances are thought to activate sub-populations of chemosensitive group III and IV muscle afferents (Djupsjöbacka, Johansson, & Bergenheim, 1994; Raja et al., 1988).

Similar findings have occurred following intramuscular injection of hypertonic saline (Thunberg, Ljubisavljevic, Djupsjöbacka, & Johansson, 2002). This activation causes reflex effects on gamma motor neurons, with further increased sensitivity of the gamma muscle spindle system to stretch and excitability of the alpha motorneuron pool creating yet more stiffness. This can result in a vicious cycle as increased muscle stiffness will result in increased production of metabolites.

This stiffness effect can be local to the muscle itself and in other muscles (in part due to the extensive network provided by secondary muscle afferents), and also in contralateral muscles (Djupsjöbacka et al., 1994; Djupsjöbacka, Johansson, Bergenheim, & Sjölander, 1995). In addition, increased concentrations of bradykinin due to pain, ischaemia, or inflammation, heightens the stretch reflex response function of muscle spindles resulting in heightened activation of gamma motor neurones and further activation of the muscle spindle system, and a subsequent further increase in muscle stiffness (Djupsjöbacka, Johansson, Bergenheim, & Wenngren, 1995; Wenngren, Pedersen, Sjölander, Bergenheim, & Johansson, 1998). These sequences of events resulting in increasing muscle stiffness, appear to be involved in the onset, spread and maintenance of chronic muscle pain (Johansson et al., 1991b; Pedersen, Sjölander, Wenngren, & Johansson, 1997).

While this is an attractive hypothesis regarding chronic muscle pain, it is only supported by animal studies and needs to be demonstrated in human studies (Knutson, 2000). Recent research on humans would suggest induced pain (in tibialis anterior) actually reduced local muscle

activity, but slightly increased activity in antagonist muscles (Birznieks, Burton, & Macefield, 2008), consistant with a pain-adaptation model of muscle activation in response to pain (Lund, Donga, Widmer, & Stohler, 1991). Others have demonstrated increased muscle activation in human models in response to painful injection in erector spinae, but concluded it was not via activation of a stretch reflex response sensitisation of muscle spindles, but changes in descending motor commands. These led to a reduction in the speed and range of voluntary trunk movement, consistent with “muscle guarding” and the pain-adaptation model (Lund et al., 1991; Zedka, Prochazka, Knight, Gillard, & Gauthier, 1999).

Although only a small scale study of five healthy participants, the LBP that was induced by injection of saline into the erector spinae muscle was considered similar, to the pain experienced in people with LBP (Zedka et al., 1999). The finding that there was no increased stretch reflex response associated with the increased muscle activity that was recorded using EMG, was unexpected. It suggests that there was no increase in sensitivity of the muscle spindles to stretch when deep muscle pain was induced by saline injection.

Uncertainty remains, as to the neurophysiological response and involvement of muscle spindles or not, in people with LBP, or when pain is induced in paraspinal tissues (Clark et al., 2011; van Dieën et al., 2003b). Consequently, the relationship between neurophysiological changes involving muscle spindles and position error in the low back is uncertain. Due to the importance however, of afferent input from muscles and their muscle spindles on proprioceptive acuity, any changes in muscle spindle sensitivity and in muscle stiffness in the low back due to LBP, could alter the proprioceptive response and therefore the result of low back position sense testing.

Brain changes and effects on muscle spindles and LBP

Increased fusiomotor activity and the above consequence can also occur in response to fear and anxiety during experimental settings (Prochazka & Hulliger, 1998). Fear of pain and (re)injury (Vlaeyen et

al., 1999; Watson, Booker, & Main, 1997a), is believed to affect trunk muscle function. Alteration in trunk muscle function could alter the afferent feedback on position sense or the motor output response, leading to changes in acuity of low back position sense. As pain is experienced in the “virtual body” image held within e.g. the primary somatosensory homunculus, it is considered likely that fear of pain also influences this body image. It is possible this “virtual body” may change in response to ongoing pain and fear of pain, with postural and motor responses varying and becoming less accurate (Moseley, 2003). Any increase in fusimotor drive will increase muscle stiffness and similarly the onset, spread and maintenance of chronic muscle pain.

Little is known about the central responses occurring as a result of afferent stimulation of proprioceptive receptors in response to muscle pain or fatigue (Capra & Ro, 2000). An animal study in cats, monitoring brain stem neurons that receive proprioceptive information from muscle afferents, found painful stimulation of the jaw muscle by electrical stimulation and injection of hypertonic saline commonly decreased proprioceptive input and firing. This effect was also noted from muscles contralateral to the site of the injection, suggesting local painful stimulation is not required to alter proprioceptive firing. As the study was performed on the jaw muscles of 11 cats, it is unknown whether similar effects would occur in humans in response to LBP. The results do suggest there is altered fusimotor drive and subsequent decreased sensitivity of muscle spindle endings in response to pain. As this change in sensitivity of muscle spindle endings may be distant to the site of pain (even on the opposite side of the body), it suggests this process involves interneuron activity in the brain stem, and not just spinal level reflex activation of gamma motor neurons (Capra et al., 2000).

Muscle pain in the low back may therefore affect position awareness. This may be because of a change locally with in muscle spindles, and/or due to decrease in proprioceptive input to the higher centres involved in processing and initiation of an appropriate motor response.

Whether changes in these processes adversely affect the ability of people with LBP during testing of position sense, is unknown.

Much of what has previously been presented on the role of muscle spindles, relates to the unconscious and automatic control of posture and movement, rather than their role in conscious sense of limb position. Their unconscious role relates to the muscle spindles being the receptors for the stretch reflex and their conscious role relates to their ability to inform the CNS about muscle length (Proske, 2006). It appears that the CNS mechanism for the unconscious and conscious role of muscle spindles may be separate, although there is likely to be some interaction of the central processing of relevant information (Proske, 2006).

Evidence that these roles are processed separately in the CNS comes from studies on monkeys, where it was found that during loading approximately 50% of neurons activated in the primary motor cortex did so wholly for postural or movement tasks. Those neurons that were activated in loading during both postural and movement tasks, were found to be able to switch the size of their response between postural and movement tasks (Kurtzer et al., 2005). In addition, activation of different cortical sites in the premotor and primary motor cortex, led to monkeys adopting different postures (Graziano, Taylor, & Moore, 2002). The awareness of posture would therefore appear very important for the brain. This finding supports the believe that this information is processed separately from movement sense within the brain (Proske, 2006). The postures that were reproduced related to the limbs and face. It remains to be investigated whether; specific static and dynamic postures of the trunk could be reproduced with similar stimulation of different neurons in the primary motor cortex.

Other studies have also suggested it is likely there are separate central processing mechanisms for afferent information on position and movement sense (Walsh, Hesse, Morgan, & Proske, 2004). Although it involved the upper limb, five participants without pain, performed six sets of 75 repetitive movements of the hand from a specific start

positions to a specific target position. The results demonstrated movement distance and direction remained precise, but there was drift of the start position - average of 8cm drift at each start position (Brown, Rosenbaum, & Sainburg, 2003). It is unknown whether similar findings would occur in the trunk in people with and without LBP and how this might effect testing of position sense in the low back. The possibility that there are separate central processing mechanisms for afferent information on position and movement sense, may suggest that if LBP is not found to result in deficits in position sense, deficits may still occur in movement sense, or vice versa.

1.2.2.4 Decreased muscle endurance, LBP and position sense

In human studies, reduced endurance of trunk extensor muscles and back extensor muscle fatigue, are common in patients with LBP (Luoto, Heliövaara, Hurri, & Alaranta, 1995; Mannion, Connolly, Wood, & Dolan, 1997a; Roy, De Luca, & Casavant, 1989). Others also report decreased trunk flexor strength and endurance, and trunk extensor muscle endurance in LBP (Biering-Sørensen, 1984; Suzuki & Endo, 1983). With less ability to develop trunk muscle force in response to sudden loads (Wilder et al., 1996), the spine is therefore vulnerable to injury and on-going pain (Biering-Sørensen, 1984; Mannion et al., 1997a).

Any decreases in trunk muscle endurance could be due to habitual repetitive loading of spinal tissue (associated with less activity in the deep trunk muscles) (O'Sullivan et al., 2002; O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006). It is also possible that reduced activity itself leads to disuse (Moffroid, 1997; O'Sullivan et al., 2006), and is associated with altered patterns of motor control (O'Sullivan, Twomey, & Allison, 1997a). This decreased muscle endurance in the low back, would therefore increase stress on spinal tissues, by simply causing poor posture (e.g. slump sitting) which in turn, increases loading on spinal tissue (Panjabi, 2006). These changes in trunk muscle endurance could also be associated with deficits in position sense, because of the importance of afferent information from muscle on proprioceptive acuity.

1.2.2.5 Muscle fatigue, LBP and position sense

Fatigue in muscle can be considered as loss of the ability to produce muscle force following an activity related to a maximal contraction, caused by both peripheral and central mechanisms (Gandevia, 2001; Selen, Beek, & van Dieën, 2007). Animal models have found fatigue, induced by electrical stimulation, decreases sensitivity, and static and dynamic response of Golgi tendon organs (GTO) (Hutton & Nelson, 1986). Decreased sensitivity occurs also in muscle spindles in response to ischemia, hypoxia and lactic acid found during fatigue (Graham, Jammes, Delpierre, Grimaud, & Roussos, 1986; Lagier-Tessonnier, Balzamo, & Jammes, 1993). Similar response changes in Golgi tendon organs and muscle spindles in humans would potentially decrease position awareness. Other animal studies however, have reported that muscle spindle sensitivity to stretch is increased during recovery from fatigue (Nelson & Hutton, 1985). These changes to the GTOs and muscle spindles will potentially lead to alterations in position sense as a consequence of muscle fatigue. Whether in response to muscle fatigue, similarities in position sense occur between people with and without LBP, or it results in greater deficits in people without LBP, remains unclear.

Muscle fatigue has been shown to impair proprioceptive acuity in the elbow, shoulder and knee in healthy participants (Allen & Proske, 2006; Carpenter, Blasier, & Pellizzon, 1998; Lattanzio, Petrella, Sproule, & Fowler, 1997; Skinner, Wyatt, Hodgdon, Conard, & Barrack, 1986). Studies into the back, have also found that fatigue of muscles, decreases proprioceptive acuity in healthy NLBP participants (Brumagne, Lysens, Swinnen, & Charlier, 1999a; Hurley, Clifford, & Murphy, 2000). Although relatively small scale research, these two studies suggest exercise-induced fatigue has a negative effect on low back position sense in participants without LBP. Similarly, a study investigating the ability of working people, with and without LBP, to sense passive lumbar rotation, found it was poorer in all people after a back extension fatiguing protocol against resistance, particularly in those with LBP (Taimela, Kankaanpää, & Luoto, 1999).

1.2.3 Control of joint movement and posture is vital to minimise the potential for LBP

Joint stiffness and the sensory role of muscle spindles

Passive joint stiffness is a function of ligaments, other joint structures, joint geometry and friction between cartilage surfaces. Mechanoreceptors and nociceptive receptors provide feedback to the CNS and are found throughout the spine in the disc annulus, ligaments and facet joint capsules (Bogduk, 1997). In addition, further stiffness is caused by compression caused by gravitational load and muscle action. The segmental muscles of the low back are densely populated with muscle spindles (Amonoo-Kuofi, 1983), and action of these muscles causes considerable joint loading and is crucial in providing dynamic control of joint movement during functional tasks by increasing joint stiffness. In addition, TrA is reported to have a very high relative abundance of muscle spindles, which in humans is exceeded only by the muscles of the neck (Banks, 2006) and a very high density of muscle spindles in proportion to its mass when compared to other trunk muscles (Kokkorogiannis, 2004). This may indicate that TrA has a very important sensory role. Valuable proprioceptive and nociceptive information is therefore capable of being transmitted to the CNS, from both muscle and joint structures in the low back. Under normal circumstances with no LBP, initiation of a normal trunk muscle response is required to control of spinal posture and balance, and minimise stress on spinal tissue.

Extremes of range and reflex muscle action

At extremes of motion where structures may be vulnerable to injury, slow-adapting proprioceptive receptors, found in joint structures, such as Ruffini receptor endings and Golgi tendon organ-like endings, appear to be maximally stimulated (Grigg, 1994; Zimny, 1988). As a consequence, it has been suggested that proprioceptive feedback from joint structures is better towards end-range when ligaments are towards their maximum length, for example in knee extension (Borsa,

Lephart, Irrgang, Safran, & Fu, 1997; Fridén, Roberts, Zätterström, Lindstrand, & Moritz, 1996). This is likely to be a response to the protective role of these proprioceptive receptors and the need to avoid end range loading. Although they play a major role in conscious awareness of joint position, these receptors also initiate reflex muscle contractions aiding control of joint stiffness and functional movement (Freeman & Wyke, 1964; Grigg, 1994; Proske et al., 2009). Similarly, rapidly-adapting Pacinian corpuscles, found throughout joint structures, respond to changes in acceleration and initiate brief protective reflex muscle contractions (Zimny, 1988).

Spinal anatomical structures and reflex muscle activation

In animal studies, stimulation of low threshold nerve endings in the posterolateral and lateral anulus of the disc and facet joints, activates paraspinal muscles via spinal reflexes (Indahl, Kaigle, Reikerås, & Holm, 1995; Indahl, Kaigle, Reikerås, & Holm, 1997). Similar findings have been found in animal and human studies on stimulating supraspinous ligaments (Solomonow, Zhou, Harris, Lu, & Baratta, 1998). This may be consistent with repetitive and prolonged habitual loading caused by poor posture e.g. slumped sitting.

These complex reflexes, from nerve endings in spinal ligaments, disc, facet joints and muscles, convey proprioceptive afferent information, resulting in reflex muscle activation patterns that control normal spinal movement. This will protect the spine from mechanical injury, although long-term muscular contraction could be a source of pain through for example, ischaemic changes (Indahl et al., 1995; Indahl et al., 1997). Deficits in proprioceptive afferent information corrupt these spinal reflexes and consequently automatic, unconscious, local postural readjustments are affected and they no longer protect the spine from mechanical injury. Consequently, reduced proprioceptive acuity in the low back may be a precursor to injuries to the back and subsequent LBP. Whether these unconscious responses to deficits in afferent proprioceptive information, would be reflected in deficits in position sense testing to “target” position which requires conscious thought processes, is unknown.

Muscle contraction and stimulation of joint afferents

It is also suggested that muscles crossing closely to joints stimulate joint afferents when contracting, due to their possible anatomical connections to joint structures. Examples of this are that gastrocnemius arises in part from the knee joint capsule (Grigg, 1975), and semimembranosus attaches to the posterior oblique ligament (Hughston & Barrett, 1983). Furthermore, gamma motor neurons receive constant information from joint mechanoreceptors, and via the gamma motor neuron loop they contribute to the pre-programming of muscle stiffness. This process influences joint stiffness and control during functional movement (Johansson, 1991). The fusimotor system consisting of the muscle spindles and their efferent gamma motor neurons, is therefore influenced by joint as well as muscle, and even skin afferents.

Proprioceptive information and protection of joints from injury and pain

It is debatable whether reflex muscle contraction is fast enough to consistently protect joints from injury. Certainly, it has been shown that contracting muscles at a joint can significantly increase ligament stiffness and provide protection from injury. At the knee it was reported that contraction of sartorius and vastus medialis, substantially increases valgus stiffness (Pope, Johnson, Brown, & Tighe, 1979). Also at the knee, when the anterior cruciate ligament (ACL) is stressed, there is reflex activation of hamstrings and inhibition of quadriceps (Solomonow et al., 1987). It is likely reflex muscle contraction protects a joint like the knee during walking and jogging, due to high conduction velocities of proprioceptive afferents. However, during fast functional movements, the conduction velocities are likely to be too slow to allow reflex muscle protection to occur (Johansson, 1991; Ting et al., 2009).

It is therefore unlikely at high loads or high speed, whether the proprioceptive input that creates a reflex muscular contraction and extra stiffness, for example at the knee, is great enough to enable a joint to withstand injury (Johansson, 1991). Under these conditions

feed-forward (preparatory/anticipatory) motor control mechanisms will be particularly important. Whether conduction velocities of proprioceptive afferents are fast enough at the spine for reflex muscle protection to be effective during very fast functional movements or high loading is unknown, as the distance travelled during a monosynaptic spinal reflex (spinal joint to spinal muscle) would be less than in the limbs, where much of the research has occurred.

Poor posture, LBP and position sense

People can develop LBP because of prolonged maintenance of poor posture (Pope, Goh, & Magnusson, 2002), such as slumped sitting. Adopting this posture decreases muscle activity in the back and transverse abdominal wall - TrA (O'Sullivan et al., 2002). Their importance for proprioceptive acuity is shown by the large number of muscle spindles within these deep trunk muscles (Amonoo-Kuofi, 1983; Kokkorogiannis, 2004). They are (in part) responsible for maintaining the neutral spinal posture and thus help reduce load on passive structures, (Goel, Kong, Han, Weinstein, & Gilbertson, 1993).

Similarly, biomechanical modelling has shown that under compressive loading of 2800N, the flattening of an excessive lumbar lordosis by 16 to 20 degrees to a more neutral posture, significantly decreases: muscle forces (50N/m to 1N/m); facet joint forces; and shear forces on discs (Shirazi-Adl, Sadouk, Parnianpour, Pop, & El-Rich, 2002). The decrease in muscle forces required in neutral postures, also helps minimise muscle fatigue and maximise their endurance capabilities (Shirazi-Adl et al., 2002; van Dieën, 1997).

Accurate position awareness is therefore important because habitual poor posture (slumped or excessive lordosis) will cause prolonged abnormal joint loading. This repetitive stress to innervated tissues like spinal ligaments, joint capsules and disc annulus, decreases protective muscle activation (Solomonow, Zhou, Baratta, Lu, & Harris, 1999), predisposing the spine to possible injury and pain (Panjabi, 2006), and acceleration of degenerative changes (Reeves et al., 2009). Figure 1:7 depicts a possible mechanism, linking this process to decreased sensorimotor control.

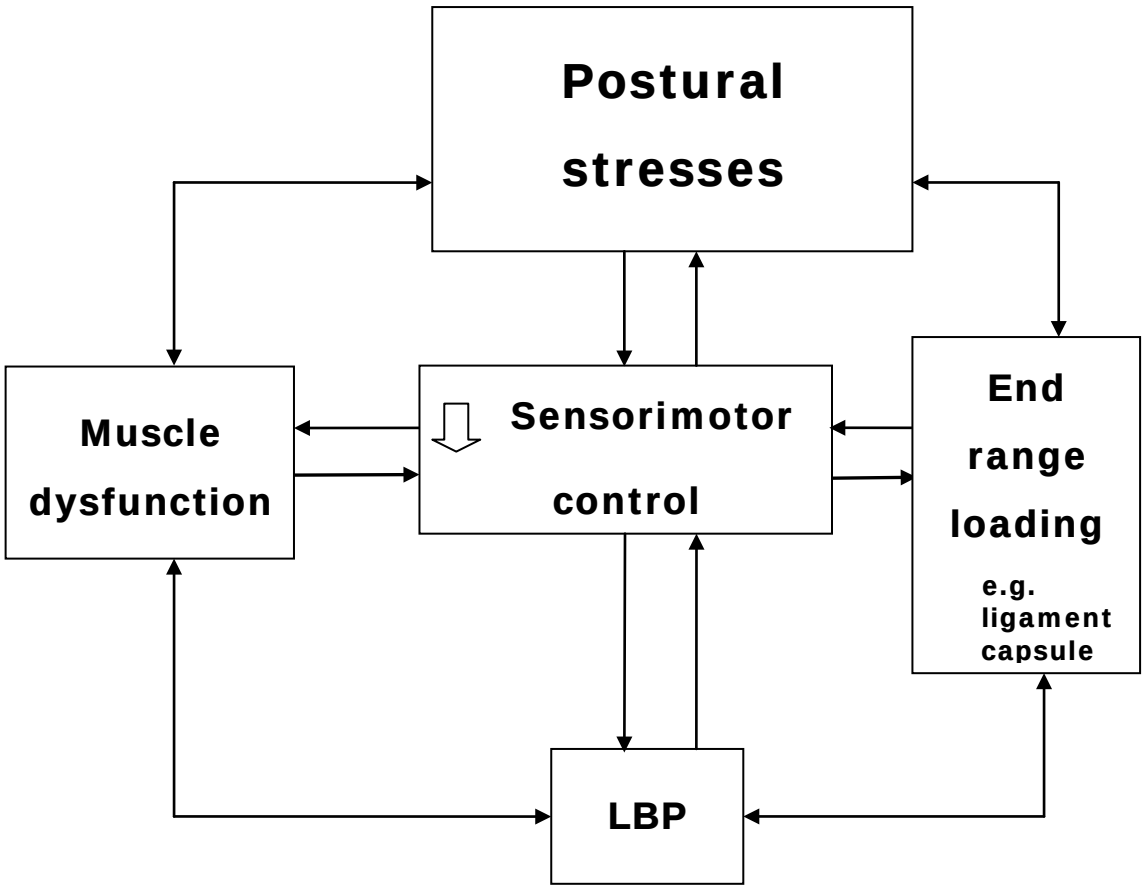


Figure 1:7. Linking postural stresses to end range loading, LBP and decreased sensorimotor control

There are obvious difficulties with studies of biomechanical models in the lumbar spine (van Dieën, 1997). Modelling often lacks the thoracic passive spine and the larger trunk muscles that traverse the lumbar spine. These types of studies however, remain very important in the absence of non-invasive methods to measure muscle forces and load distribution (Shirazi-Adl et al., 2002). They also provide important theoretical information, helping to develop ideas for clinically based studies and possible explanations for clinical findings.

Habitual repetitive poor posture in sitting, combined with a lack of physical activity due to prolonged sitting, have previously been suggested as possible reasons for an association between LBP and watching TV in adolescents (Balagué et al., 1994; Balagué, Troussier, & Salminen, 1999). Only prospective studies however, would determine whether these factors are predictors of onset of LBP or consequences of the pain itself. In a study of 1046 schoolchildren, aged 11 to 14 years who were free of LBP at onset, it was found at a one-year follow-up that time spent watching TV or computer games, or participating in general physical activity at schools, was not a predictor of onset of LBP (Jones, Watson, Silman, Symmons, & Macfarlane, 2003). Further prospective studies are needed to investigate for an association, perhaps with a longer-term follow-up as LBP is more common in increasing age (Balagué et al., 1999).

In a study of 24 industrial workers with flexion-related low back pain, it was found they sat closer to end-range flexion when compared to 21 similar workers with no LBP (O'Sullivan et al., 2006). Participants with LBP also had significantly reduced back muscle endurance. Although it was a small sample size, the findings suggest a relationship between flexed spinal postures, decreased back muscle endurance, physical inactivity and LBP provoked by flexion. Sitting closer to end-range of a provocative movement – in this case lumbar flexion - is a possible mal-adaptive response that was also found in a previous study investigating position sense in participants with LBP (O'Sullivan et al., 2003). This habitual loading of pain-sensitive spinal tissue, may lead to ongoing

tissue sensitisation and maintenance of a chronic pain state (O'Sullivan et al., 2006).

The potential consequences of this are explained in a hypothesis of repetitive microtrauma to spinal ligaments. In this scenario, repetitive stretching of ligaments beyond their physiological limit increases the loading, and stresses and strains on spinal tissue. In time, this could accelerate degenerative changes (Reeves et al., 2009) to the facet joints and disc, and initiate inflammation of nerve tissue (Panjabi, 2006). With altered proprioceptive information sent to the CNS and therefore an altered efferent muscle response, poor proprioceptive acuity is therefore possible in LBP patients who sit in prolonged flexed postures when testing their low back position sense.

Prolonged flexed sitting postures which may affect endurance of the trunk muscles, has been reported to impair spinal position awareness in people without LBP (Dolan & Green, 2006). This could lead to poor responses to sudden loading and movement, and potential injury and pain. It is yet to be determined, whether prolonged flexed sitting posture impairs spinal position awareness in people with LBP, thereby possibly contributing to ongoing or recurrent episodes of back pain. It is also yet to be determined, whether any effects on spinal position sense are more likely to occur in a specific population of workers, exposed to particular occupational risk factors, including prolonged flexed low back postures in sitting or jobs involving bending e.g. sedentary workers, drivers or manual workers.

1.2.4 Brain changes and LBP

The effects in the brain due to longstanding pain are not clearly understood and remain to be fully investigated. In chronic pain, representation of body parts and movement in the primary sensory and motor cortices is altered, affecting sensory awareness and motor outputs (Lotze & Moseley, 2007). For example, people in pain are less able to identify tactile stimulation applied to their painful body part. This change is associated with reorganisation in the primary somatosensory cortex (Maihöfner, Neundörfer, Birklein, & Handwerker, 2006; Moriwaki & Yuge, 1999).

Preliminary evidence in people with chronic LBP, showed that none of the ten controls and all six patients drew distorted body images of their trunk outline and spinous processes (Moseley, 2008a). Two-point discrimination was also diminished in areas of absence, or disruption of body image, coinciding with the location of back pain. A similar loss in two-point discrimination over the low back in 19 people with LBP compared to 19 people without LBP has recently been reported (Wand, Pietro, George, & O'Connell, 2010b). In addition, 21 people with LBP (particularly if they had bilateral LBP) were less accurate at identifying images of left / right trunk rotation than 14 people without LBP (Bray & Moseley, 2010). A further study of 45 people with and 45 without LBP, reported that two-point discrimination over the low back had a mean threshold score between the two-points of 61mm in people with LBP against 44mm for healthy controls (Luomajoki et al., 2010).

This localised disruption in two-point discrimination and of body image is likely to be related to alterations in the sensory input from the area (including proprioceptive), with cortical representation (a body map) of the back in people with LBP different to healthy controls (Flor et al., 1997). Whether this reorganisation in the primary somatosensory cortex is reversible or permanent in people with LBP is unclear, but there is evidence to suggest it is reversible in complex regional pain syndrome and is associated with a decrease in pain (Pleger et al., 2005). Alteration in central representation of posture in the sensory

cortex due to pain may be another potential cause of a decrease in proprioceptive acuity (Prud'homme & Kalaska, 1994). Measuring proprioceptive acuity along with monitoring brain activity and its location should be considered, both before and after attempts to reverse these changes in the brain. Any association with changes in pain can then be considered.

With pain and inflammation altering the afferent information on position and movement sense to the CNS (Schaible et al., 1985), and causing changes to the sensory cortex, this could lead to alterations in motor control response initiated by the cortex, resulting in abnormal movement patterns, abnormal joint loading and further pain. These abnormal movement responses could also alter the motor performance required during position sense testing.

In a study of 10 people with chronic LBP (with low levels of pain and disability at the time of testing) and 10 healthy participants, EEG recordings, suggest LBP is associated with changes in motor activity in the cerebral cortex that occurred prior to voluntary arm lifts (Jacobs, Henry, & Nagle, 2010). There was evidence of bilateral cerebrocortical motor activity prior to known voluntary arm movements in people with LBP, but this activity only occurs in midline and contralaterally in the brain in people with NLBP. These changes in EEG appear to be associated with delayed activation of the erector spinae and internal oblique muscles as recorded by surface EMG, which may contribute to ongoing or recurrence of LBP. As EEG records when neuronal activity occurs (Moseley, 2008b), further studies are needed that can identify where in the brain these changes are occurring.

The use of Transcranial Magnetic Stimulation (TMS) is one method of attempting to locate neuronal activity. In a study of 11 people with recurrent NSLBP lasting longer than 3 months, and 11 people without LBP, motor thresholds in the brain were measured using TMS (Tsao et al., 2008a). It was reported that the size of the TMS motor cortical map was larger and its centre located more posteriorly and laterally than in

healthy individuals. This was associated with slower onset of transversus abdominus activation recorded by fine-wire EMG during rapid arm movements, suggesting that the changes in neuronal activity in the motor cortex may be involved in deficits in feed-forward postural control (Tsao et al., 2008a). The use of fMRI in association with TMS is likely to increase the accuracy of cortical mapping and is needed in order to confirm these findings.

Other studies, have reported decreased corticospinal excitability recorded using TMS in 24 people with chronic LBP, diagnosed with a L4/5 disc pathology, when compared to 11 people without LBP (Strutton et al., 2005). TMS recordings were made as participants lay prone and maintained 20% of a maximum voluntary contraction (MVC) of erector spinae, recorded using EMG. This decreased corticospinal excitability may be an attempt to relax the muscle close to the site of pain, to help lessen symptoms. Alternatively, this change in corticospinal excitability may signify altered control of the back muscles and lead to LBP. A similar finding of decreased corticospinal activity has been reported in people with unilateral sciatica (Strutton et al., 2003). In this study, TMS was recorded in 9 people with unilateral sciatica and compared to 7 people without LBP. TMS recordings were made with participants seated and maintaining 20% of a MVC of tibialis anterior and gastocnemius, recorded using EMG. Further research is needed to investigate whether decreased corticospinal activity in people with LBP occurs during painful or non-painful functional movements.

These alterations in cerebrocortical motor activity and subsequent changes in trunk muscle activity could alter the motor response that controls posture and movement. This could result in deficits in the ability of trunk muscles to accurately relocate to target positions during position sense testing. In future studies, it may be useful to measure motor activity in the cortex and investigate the sensory cortical map, to see if there are differences in these, in people with and without LBP during position sense testing.

1.2.5 Proprioceptive impairment in peripheral joints

Anaesthetisation of joints has been shown to decrease proprioceptive acuity (Ferrell et al., 1992a; Ferrell et al., 1989; Gandevia et al., 1983), as has damage to the ACL of the knee (Barrack et al., 1989; Barrett, 1991; Corrigan et al., 1992). Interestingly, it has been suggested proprioceptive function in the contralateral limb can also be affected by ipsilateral joint injury (Jerosch & Prymka, 1996; Zätterström, Fridén, Lindstrand, & Moritz, 1994). The mechanism of this is uncertain, although the mechanisms associated with contralateral muscle spindle sensitisation following muscle pain are of interest (see section 1.2.2.3). Central processes in response to pain or inflammation could also be involved, whereby altered afferent information affects the firing of neurons at higher level in the CNS. In an animal study by Capra et al., (2000), they found when pain and swelling was induced in the jaw muscles on one side, there was decreased proprioceptive input from muscle afferents and firing of brain stem neurons. This affect was also noted from the contralateral muscles, suggesting local pain and swelling is not required to alter proprioceptive firing.

Reduced joint position awareness in peripheral joints has been found in chronic joint conditions (Guido, Voight, Blackburn, Kidder, & Nord, 1997; Hurley et al., 1997), at the knee, ankle, shoulder and fingers (Hurley, 1999). This is believed to be due to impaired proprioceptive information from muscle spindles in the periarticular muscles. Vibration (Inglis, Frank, & Inglis, 1991; Roll, Vedel, & Ribot, 1989) and fatigue (Lattanzio et al., 1997; Skinner et al., 1986), can also impair proprioceptive information generated by these muscle spindles and thus reduce joint position awareness. Studies have also demonstrated proprioceptive deficits due to hypermobility (Hall, Ferrell, Sturrock, Hamblen, & Baxendale, 1995; Mallik, Ferrell, McDonald, & Sturrock, 1994) and normal ageing occurring from the mid to late sixties (Ferrell, Crighton, & Sturrock, 1992b; Hurley, Rees, & Newham, 1998a; Pai, Rymer, Chang, & Sharma, 1997). As increasing age has a detrimental effect on proprioceptive acuity, it needs to be considered when

designing and interpreting the results of similar studies. An upper age limit of 60 years is likely to minimise the possibility of participants having age-related decreases in position sense.

Following ligament and capsule injuries in the knee, reflex muscle contraction is diminished (Attfield et al., 1996; Sjölander et al., 2002; Solomonow et al., 1987). It is suggested there is a loss of feedback from mechanoreceptors (including proprioceptors) in knee ligaments, following their injury. This alters the co-ordinated efferent motor response and contributes to repetitive trauma and progressive instability of the knee joint (Kennedy et al., 1982). Alterations in muscle activation also occur, with there being earlier recruitment and prolonged activity especially in the hamstrings and gastrocnemius muscles during walking uphill (Kålund et al., 1990; Lass et al., 1991).

These alterations in coordination patterns, may be a compensatory effect in an attempt to maximise joint control in ligament deficient patients (Sinkjaer & Arendt-Nielson, 1991). Variation in the afferent feedback from injured ligaments is also said to result in decreased functional joint control, due to errors in normal motor coordination patterns (Johansson, 1991; Johansson et al., 1991a; Kennedy et al., 1982). In addition, altered kinematics have been found in ACL-deficient knees (McNair, Marshall, & Matheson, 1989) and subsequent repair has actually resulted in improvements in proprioceptive ability (Barrett, 1991; Jerosch et al., 1996).

1.2.6 Proprioceptive impairment in the spine

In comparison to the limbs, there have been fewer investigations into the role of proprioceptive information in the protection and normal functioning of vertebral joints, even though maintenance of a good spinal posture requires an intact proprioceptive input from accurate body awareness.

1.2.6.1 Accuracy of position sense

Differences in position sense between 20 people with chronic LBP lasting greater than 1-year and 20 without LBP, have been found when attempting to reproduce predetermined target angles in standing and four point kneeling (Gill et al., 1998). Similar differences have also been found in sitting prior to applying vibration to muscle spindles in multifidus in 23 young participants with LBP (defined only as mechanical LBP and no information was given on its duration) and 21 without LBP (mean age in early 20s years, in all participants), (Brumagne et al., 2000). In addition, greater difficulty has been found when repositioning to a neutral spine in sitting in 15 people with LBP and a clinical diagnosis of lumbar segmental instability, compared to 15 individuals with no LBP (O'Sullivan et al., 2003).

In contrast, other studies have not found greater errors in position sense when testing 20 people with “mechanical” LBP, of at least 3-months duration, attempting to reposition to a neutral spine in sitting (Lam et al., 1999; Maffey-Ward, Jull, & Wellington, 1996). Similarly, no differences were found in 16 people with chronic recurrent non-specific LBP of at least 6 months and 15 people without LBP (Descarreaux et al., 2005).

A major difficulty in comparing the findings of these studies, is the use of different measuring equipment applied to different parts of the low back and a difference in the unit of measure. Researchers have used a:

1. piezoresistive electrogoniometer applied to the sacrum measuring degrees (Brumagne et al., 2000; Brumagne et al., 1999b)
2. Fastrak electromagnetic device measuring anteroposterior and superoinferior translations in centimetres between T12 to S2 (O'Sullivan et al., 2003)
3. Fastrak measuring degrees of movement in the sagittal, coronal and transverse planes between T10 to S2 (Lam et al., 1999) and L1 to S1 (Newcomer et al., 2000)
4. rehabilitation device used in standing measuring degrees (Descarreaux et al., 2005)
5. lumbar motion monitor between T7 and the pelvis measuring degrees (Gill et al., 1998).

Limitations of studies need to be considered when interpreting results. These include: recruitment of participants aged up to 74 years (Gill et al., 1998), yet increasing age has been shown to have a detrimental effect on the proprioceptive acuity (Hurley et al., 1998a); inappropriate NLBP control groups containing participants with a history of up to 3 months LBP (Newcomer et al., 2000), or previous LBP, provided none was present at the time of testing (Gill et al., 1998); and small numbers of participants – 16 people with chronic recurrent LBP and 15 without LBP (Descarreaux et al., 2005), and 15 people with chronic or recurrent LBP longer than 3 months and 15 without LBP (O'Sullivan et al., 2003). Moreover, spinal proprioception has not always been assessed in functional positions (Gill et al., 1998) and often only in standing (Newcomer et al., 2000; Swinkels et al., 2000), making the relevance of their results to normal function and activities unclear.

Research investigating proprioceptive acuity in the spine in a large sample size is warrented. In addition, research is needed to further investigate proprioceptive acuity in and around the neutral spinal posture, where the muscles of the trunk would be a primary informant of position sense. Low back pain can adversely affect these muscles in terms of their size, activation and function. If poor awareness of this neutral spinal position occurs in a LBP population, there is a theoretical

mechanism that could lead to onset or maintenance of LBP due to habitual end-range loading of pain-sensitive spinal tissue (O'Sullivan et al., 2006; Panjabi, 2006).

1.2.6.2 Postural control of the trunk

Postural control is an integration of the proprioceptive, visual and vestibular senses in the CNS. Disturbances in postural control and decreased reaction times have been found in people with LBP (Luoto et al., 1996; Taimela, Österman, Alaranta, Soukka, & Kujala, 1993). This impairment of postural control, results in a decreased ability to react to alterations in trunk posture (Radebold et al., 2001) and poorer balance (Mientjes & Frank, 1999). This is demonstrated particularly when standing on an uneven surface without vision and with the addition of arm movements (Brumagne, Janssens, Knapen, Claeys, & Suuden-Johanson, 2008), in 21 people with recurrent non-specific LBP and 23 people without LBP. The result is people with LBP sway more on uneven surfaces, but paradoxically hold their trunks very stiffly (van Dieën et al., 2003b), relying primarily on proprioceptive input from the muscles of the lower leg, to control standing posture on both level and on uneven surfaces. Conversely, healthy individuals rely on greater sensory input from the back muscles when standing on uneven surfaces (Brumagne et al., 2008). Although this study involved young people, experiencing relatively low levels of disability, it suggests people with LBP may be vulnerable to increased low back stresses and loads as postural instability is increased.

Recent research confirms that people with LBP rely primarily on proprioceptive input from muscles at the ankle, rather than the back to control posture in standing (Janssens, Brumagne, Polspoel, Troosters, & McConnell, 2010). This study was a small scale with sixteen young people experiencing LBP and twelve without. It found that when the inspiratory muscles in people without LBP, were fatigued using a POWERbreathe mouthpiece device, they also subsequently relied heavily on proprioceptive input from the ankle for their postural control when standing on an unstable base. As the diaphragm may contribute

to spinal stiffness, via an effect on intra-abdominal pressure, and mechanically through its attachments (Hodges, Eriksson, Shirley, & Gandevia, 2005), its fatigue could alter proprioceptive feedback to the CNS, leading to increased postural sway. Problems with breathing such as inspiratory muscle fatigue may be associated with, or implicated in the aetiology of LBP (Smith, Russell, & Hodges, 2006). Use of the diaphragm, a strategy commonly used as part of management of LBP, could help improve proprioceptive feedback and consequently postural control strategy in people with LBP helping to reduce postural sway.

In a larger study involving 106 people with LBP (mean age = 18.5 years) and 50 people without LBP (mean age = 19.6 years), postural sway was measured using a force plate during sitting, stable standing and unstable standing (Claeys, Brumagne, Dankaerts, Kiers, & Janssens, 2011). In addition, the subconscious role of proprioception in postural control was also investigated directly using muscle vibration of triceps surae and lumbar multifidus. The findings were similar to others (Janssens et al., 2010), with all standing conditions demonstrating greater reliance on the ankle region for postural control, rather than "multi-segmental" postural adjustments in the trunk. There was less reliance on proprioceptive afferent information from multifidus in people with LBP in all conditions tested, including sitting.

This strategy seems successful in stable standing / sitting conditions and even results in less sway compared to people without LBP in quiet standing. In unstable standing however, there is increased postural sway in people with LBP as they struggle to make fine-tuned multi-segmental postural adjustments at the trunk (Claeys et al., 2011). It is possible this is caused by decrease density of muscle spindles in their deep back muscles (Claeys et al., 2011). This decreased density of muscle spindles has been found in muscle fibres with less oxidative capacity, that have the potential to fatigue more easily, a feature found more commonly in people with LBP (Kokkorogiannis, 2004; Mannion, Weber, Dvorák, Grob, & Müntener, 1997b).

Whether measuring postural sway in sitting and standing during movement of the trunk and / or limbs, is a better measure of sensorimotor function than testing position sense, is yet to be determined. If the effect on postural control in people with LBP is a response to alterations in afferent input from muscle spindles then it is possible that measures of posture and position sense may be impaired in people with LBP. Possible variability in the CNS processing of this proprioceptive information, may however result in deficits in proprioceptive acuity in one of these tests, but not in the other.

1.3 Summary

The sensorimotor system is a complex system of physiological, neurosensory and neuromuscular systems and processes. Afferent signals from muscles, skin and joints pass along afferent pathways to the CNS where initially a motor response via spinal reflexes can occur. In the brain stem, this afferent information is integrated with information from the vestibular and visual receptors (Lephart et al., 1998; Saper, 2000). Assimilation of this information allows the motor control centres of the CNS (spinal, brain stem, cerebral cortex) to regulate voluntary and involuntary motor commands to control muscle activation during complex motor tasks, contributing to control of joint posture and movement (Lephart et al., 1997; Lephart et al., 1998).

An understanding of the sensorimotor system assists in determining whether possible alterations in spinal position sense have an important role in the complex biopsychosocial problem of LBP. Theoretically, if deficits in spinal position sense are apparent in people with LBP, it may lead to abnormal muscle activity and alterations in joint loading. This will result in further LBP and a vicious cycle of neurophysiological responses, commonly seen in chronic pain conditions.

If trunk muscles are dysfunctional due to low back pain (Hides et al., 1996; Hodges et al., 1996) and/or work-related activity (e.g. repetitive poor posture in sitting) and fatigue (Hurley et al., 2000), a decrease in muscle spindle sensitivity might impair people's ability to discriminate

low back position sense. This may lead to resultant poor posture associated with slump sitting or during physical activities at work. Clearly, poor posture will stress innervated tissues, causing abnormal repetitive habitual loading, and potentially lead to pain or aggravation of existing LBP (Bovenzi & Zadini, 1992; Keyserling, 2000; Kumar, 1990) and possible joint damage.

Therefore, maintenance of poor posture or exposure to occupational-related activities (e.g. lifting, vibration, or bending) may cause or aggravate LBP (Bovenzi et al., 1992; Keyserling, 2000; Kumar, 1990), possibly by reducing muscle spindle sensitivity, which impairs spinal position awareness. Thus, people whose occupations predominantly involve prolonged sitting, driving or heavy manual work, may be at increased risk of joint damage and pain if exposure to vibration, tasks that challenge trunk muscle endurance and poor posture impairs their spinal position awareness and compromises their ability to detect and react to harmful abnormal vertebral movement.

A study on the effect of exposure to poor posture in sitting, on position sense in the low back, investigated 32 healthy individuals (Dolan et al., 2006). There was only short exposure to sitting (300 seconds), in an experimental setting, rather than in the workplace (Dolan et al., 2006). Others have investigated the effect of a muscle fatigue protocol on position sense in 20 people without LBP (Hurley et al., 2000), and its effect on movement sense rather than position sense in 57 people with chronic/recurrent NSLBP of more than 3 months and 49 without LBP (Taimela et al., 1999).

It is unknown whether the possible changes in muscle spindle sensitivity and spinal position awareness would be transient, permanent or responsive to rehabilitation. Preliminary information however, from participants with NLBP suggest spinal position sense can be accurate following brief postural education (Dolan et al., 2006). Others report that only 10-minutes of training involving active use of the muscles, can improve upper limb position sense in healthy

individuals that can last until re-testing 24 hours later. Interestingly, the same movements performed passively do not result in any improvements in position sense. As the sensory changes appears to be dependent on active movement, it suggests that motor learning has a central role in the plasticity of the sensorimotor system (Ostry, Darainy, Mattar, Wong, & Gribble, 2010).

Research indicates a possible link between spinal proprioceptive acuity and LBP. The paucity of research however, impairs our understanding of involvement of position sense deficits in spinal tissue loading of pain-sensitive structures and the pathology of LBP. Improving understanding of the relationship of spinal proprioception in the assessment and management of patients with LBP remain critical (Saal, 2000).

Studies are therefore needed that investigate low back position sense in participants with and without LBP, following possible exposure to risk factors at work such as poor posture, vibration and prolonged trunk muscle activity that potentially decrease proprioceptive acuity. It would also be useful to investigate the effects on spinal position sense within specific occupational groups. Exposure to muscle fatigue protocols however may not be a priority, as it does not necessarily reflect day to day functional use. In addition, studies are needed that investigate position sense in and around the neutral spinal posture, as an inability to locate and maintain a neutral spinal posture will lead to end range postures been adopted. These end range postures may lead to, or maintain LBP due to loading of pain sensitive spinal tissue (O'Sullivan et al., 2006; Panjabi, 2006).

If position sense deficits are found using the methodology / electrogoniometer used in this thesis, the relatively cheap and simple application could prove to be a useful clinical tool. This is in comparison to more complex and expensive testing of the sensorimotor system when investigating movement sense and postural sway. Future research however, will be needed to link position sense to other tests of the sensoriomotor system including measures of movement sense, postural sway, muscle activity and brain activity.

1.4 Aims of the thesis

The aims of the thesis were to investigate:

- The accuracy, stability and test-retest reliability of the back electrogoniometer (Chapter 2).
- Position awareness in the low back in participants with and without recurrent NSLBP, including test-retest reliability data (Chapters 3 to 5)
    - Before-work and after-work (Chapter 3)
    - Before-work and after-work in specific occupational groups (manual workers, sedentary workers and drivers) (Chapter 3)
    - In mid-range of movement from slump to extension in sitting (Chapter 4)
    - In relation to where people believe a “good” sitting posture is located and also their ability to return to this position (Chapter 5).
    - The relationship of their “good” sitting posture to end-range low back extension and flexion (Chapter 5).

1.5 Objectives of the thesis

The objectives of the thesis were to investigate:

- The degree of accuracy, stability and test-retest reliability of the back electrogoniometer against a calibrated device with known angular measures. Testing occurred between 0 to +/- 60 degrees at one degree increments, and at specific angles through the same range to ensure the signal stability of the measure. Testing was repeated on two days (Chapter 2).
- Position awareness in the low back in participants with and without recurrent NSLBP, including test-retest reliability data. Reposition error (error in position sense) is used as the measurement of position awareness and is measured in degrees (Chapters 3 to 5).

Studies therefore investigated if there was a difference in:

- Low back position awareness between people with recurrent NSLBP and people who have never reported LBP, before- and after a shift of work (Chapter 3)
- Low back position awareness between people with recurrent NSLBP from a specific occupational group (sedentary, drivers and manual workers) and people who have never reported LBP from the same occupational group, before- and after a shift of work (Chapter 3)
- Low back position awareness around mid-range of sagittal plane movement of the low back, between people with recurrent NSLBP and people who have never reported LBP (Chapter 4)
- The ability to accurately reposition to a “good” sitting posture between people with recurrent NSLBP and people who have never reported LBP (Chapter 5)
- The position of “good” sitting posture in relation to end-range low back sagittal movement between people with recurrent NSLBP and people who have never reported LBP (Chapter 5).

2 IN VITRO TEST-RETEST RELIABILITY OF THE ELECTROGONIOMETER

2.1 Background

Flexible electrogoniometry measures joint movement (Ball & Johnson, 1993; Ojima, Miyake, Kumashiro, Togami, & Suzuki, 1991; Walker, Myles, Nutton, & Rowe, 2001) and is easy to use, portable and relatively inexpensive (Rowe, Nicol, & Kelly, 1988). It records a true angle between its two end plates, as it works on summation of strains and does not have a centre of rotation (Rowe, Myles, Hillmann, & Hazelewood, 2001).

In vitro measurements recorded in degrees, using electrogoniometers, have been shown to be stable, accurate and repeatable, when compared to a calibrated goniometer. They therefore have the potential to give the user valid clinical data (Rowe et al., 2001).

Collectively, the results of Rowe et al., (2001) showed that during in vitro testing the electrogoniometer was accurate to within 1 to 2 degrees across ranges up to -120 to +120 degrees. In relative terms, this is between 1% and 1.5% of the measuring range. Measurement error may therefore be expected to be between 0.5 to 0.75 degrees over a range of +/- 60 degrees, which is similar to the flexion/extension range tested in this study and less than the sagittal range of low back movement in people with and without LBP.

Little variation in measurements occurs when using different electrogoniometers (variation of less than 1% of the measured value), or the same electrogoniometer (variation of less than 0.3% of the measured range), at different times and days (Rowe et al., 2001). Errors only become substantial if the electrogoniometer moves excessively (greater than 20 degrees), in another plane at the same time e.g. at right angles to the movement measured or rotation. Errors of up to 6 to 8 degrees in recording flexion / extension can occur, when the electrogoniometer is abducted at 40 degrees and subsequently

flexed/extended from 45 to 90 degrees range. Between 0 to 45 degrees flexion/extension (when in 40 degrees abduction), errors remain small at less than 2 degrees. These errors increase with greater flexion/extension range, so that by 120 degrees, errors in recording flexion/extension can be between 8 to 10 degrees. This is termed "crosstalk" (Jonsson & Johnson, 2001). If these associated movements are less than 20 degrees however, the errors remain small throughout flexion/extension range (Rowe et al., 2001).

The electrogoniometer has previously been used to measure position sense in the low back (Dolan et al., 2006; Hurley et al., 2000). Its reliability in measuring forward and backward bending movement of the low back was reported as Intraclass Correlation Coefficient (ICC) = 0.89, with a reliability coefficient value greater than 0.5 considered a reasonable expectation when examining test-retest reliability of a measure (Streiner & Norman, 2008). The mean reported difference between repeated measures was between -0.08 to +0.52 degrees (95% CI), suggesting its usefulness in detecting clinical differences in low back position sense greater than 0.5 degrees (Dolan et al., 2006).

Although there is extensive in vitro testing of the electrogoniometer compared to a calibrated measure (Rowe et al., 2001), similar testing was considered necessary in this research using the back electrogoniometer to ensure its accuracy, stability and reliability.

Aim

The aim of this study was to investigate the in vitro validity, stability and test-retest reliability of the back electrogoniometer against a calibrated device with known angular measures. Testing occurred through range at one degree increments. This was necessary because the random target positions used in Chapters 3 and 4 occur through range and any differences in reposition error between people with and without LBP, could be small (Brumagne et al., 2000; Swinkels et al., 2000). Testing also occurred at specific angles to ensure the signal stability of the measure. Testing was repeated on a separate day, to investigate whether the results were affected by dismantling, re-assembly and re-application of the equipment.

2.2 Methodology

A quantitative approach was used to compare the validity of the flexible electrogoniometer (Figure 2:1), against a calibrated measure of degrees of movement, and to compare its test-retest reliability.

2.3 Methods

The flexible M180B electrogoniometer (Figure 2:1) (Biometrics Ltd, Gwent, UK) is connected by leads to a DataLINK system (Figure 2:2) with management version 2.0 software.

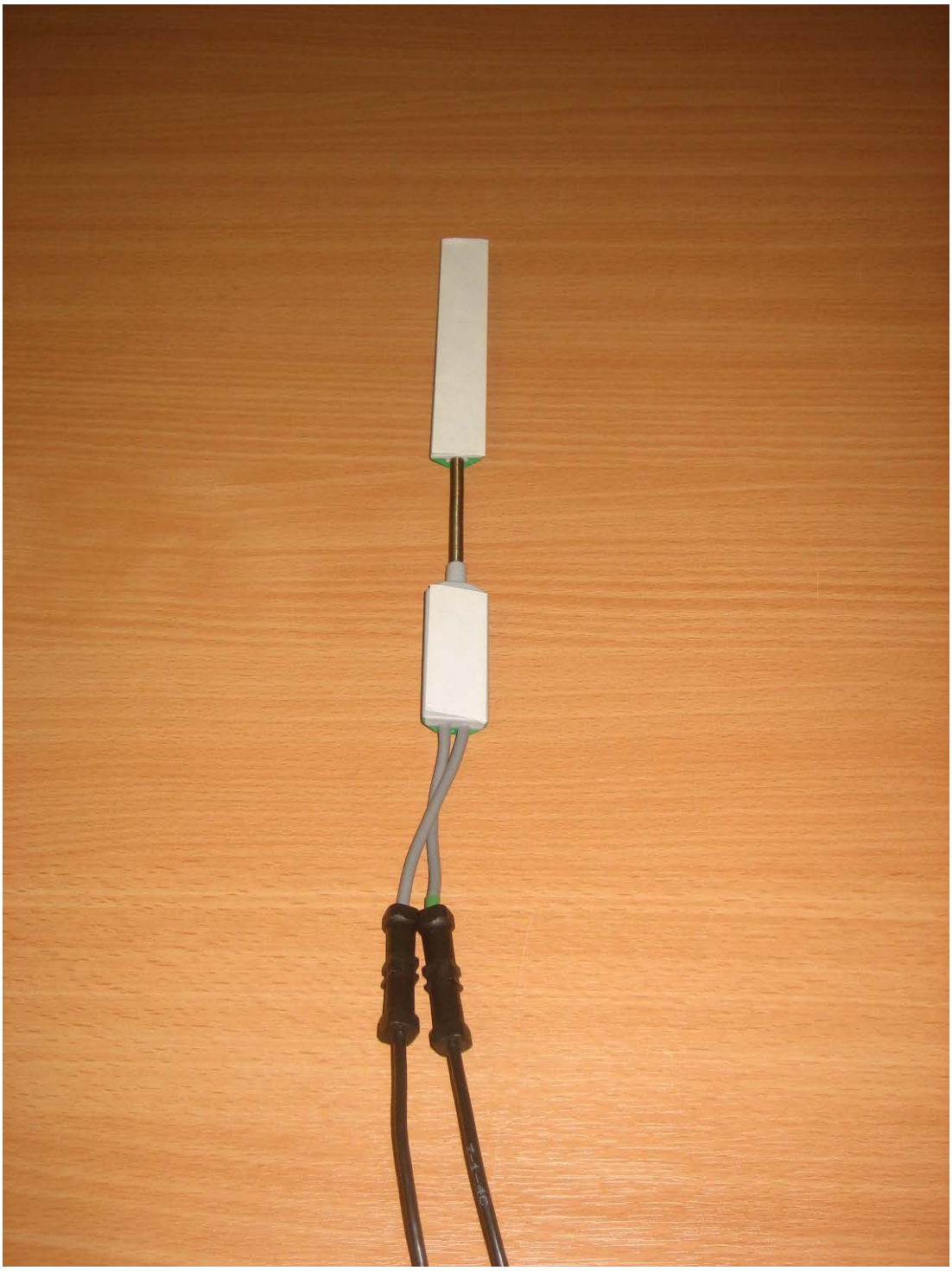


Figure 2:1. Flexible M180B electrogoniometer - Scale 1:3

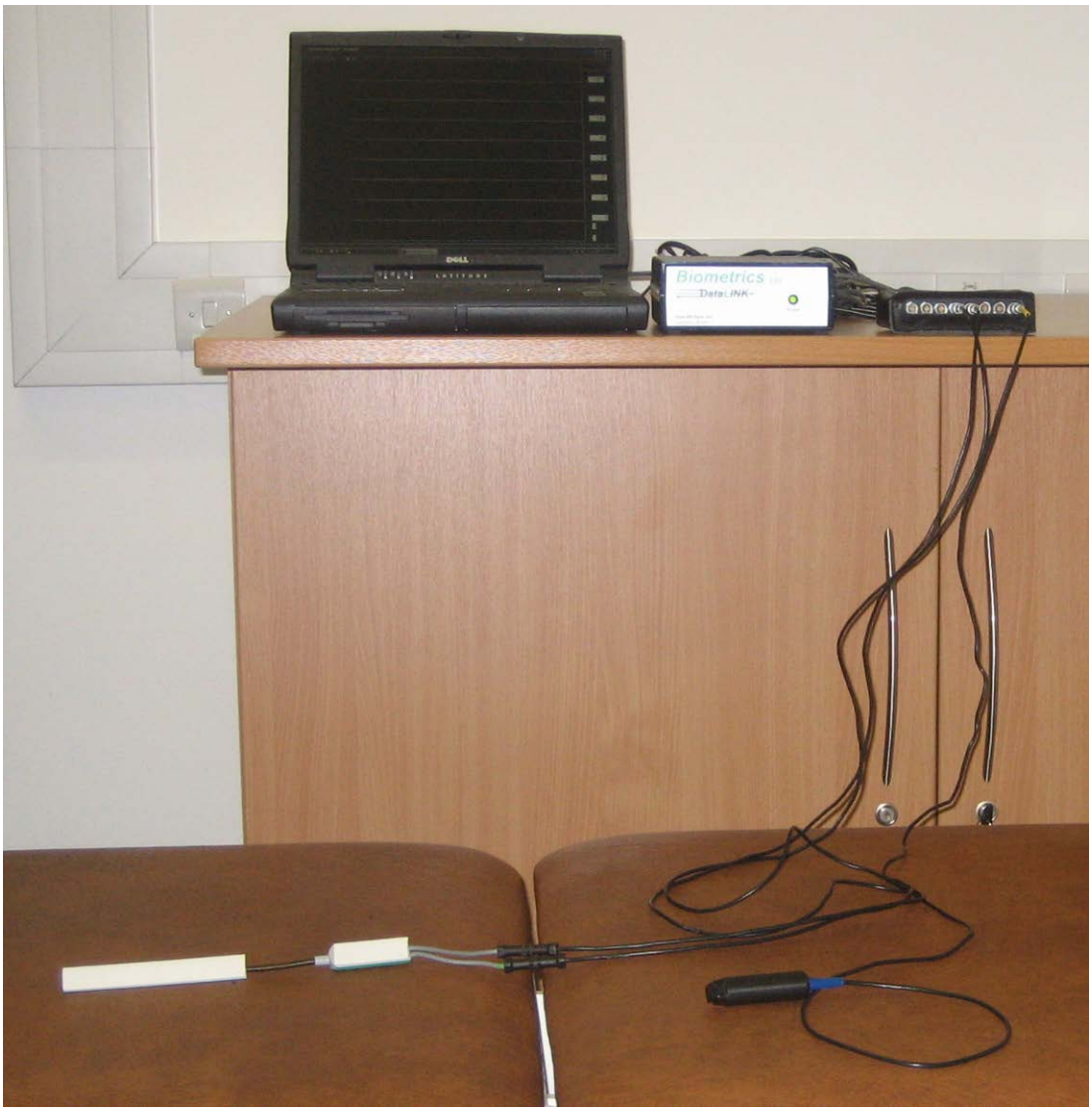


Figure 2:2. Electrogoniometer connected to a DataLINK system

2.3.1 In vitro data collection procedure

A metal arm bevel protractor (Moore & Wright; Bowers Metrology Ltd, Bradford, UK), with calibrated 1 degree stops from 0 to 90º to 0, in both directions through 360°, was used for comparison (Figure 2:3). The bevel protractor complies with BS1685:2008 Bevel Protractors (Mechanical and Optical). It features a resolution of 5 arc minutes (1/12 degree) (1 arc minute = 60^{th} of a degree) (Moore & Wright; Bowers Metrology Ltd, Bradford, UK). It has a fully hardened and ground stainless steel body with top mounted adjuster for fine setting.

The satin chrome-plated graduated scale plate enables glare-free readings and its magnifying lens allows for clear and easy reading of the flush scale (Figure 2:4). This prevents parallax errors which can result when reading an instrument with a scale and pointer i.e. when the observer's eye and pointer are not in a line perpendicular to the plane of the scale.

To ensure the current accuracy of the bevel protractor an updated Certificate of Calibration was obtained from Southern Calibration Laboratories in Southampton (Appendix 2:1).

The electrogoniometer was fixed to the arms of the bevel protractor using strong adhesive double sided sticky tape between the end plates of the electrogoniometer and the arms of the bevel protractor. Single sided adhesive tape was also attached around the end plates of the electrogoniometer and arms of the bevel protractor to help further limit the possibility of any movement.

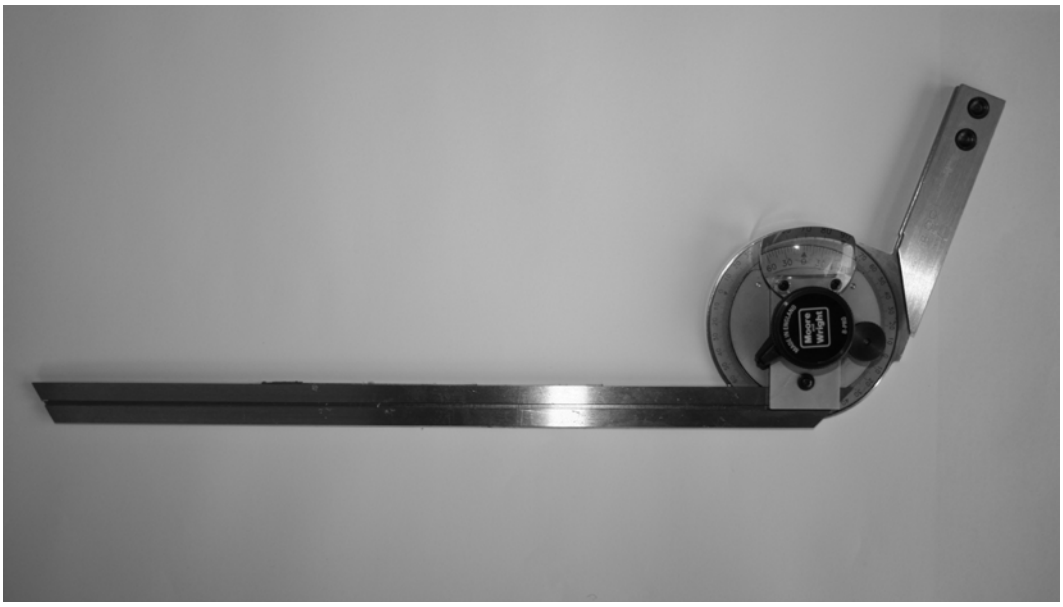


Figure 2:3. A metal arm bevel protractor – Scale 1:3
(Moore & Wright; Bowers Metrology Ltd, Bradford, UK)

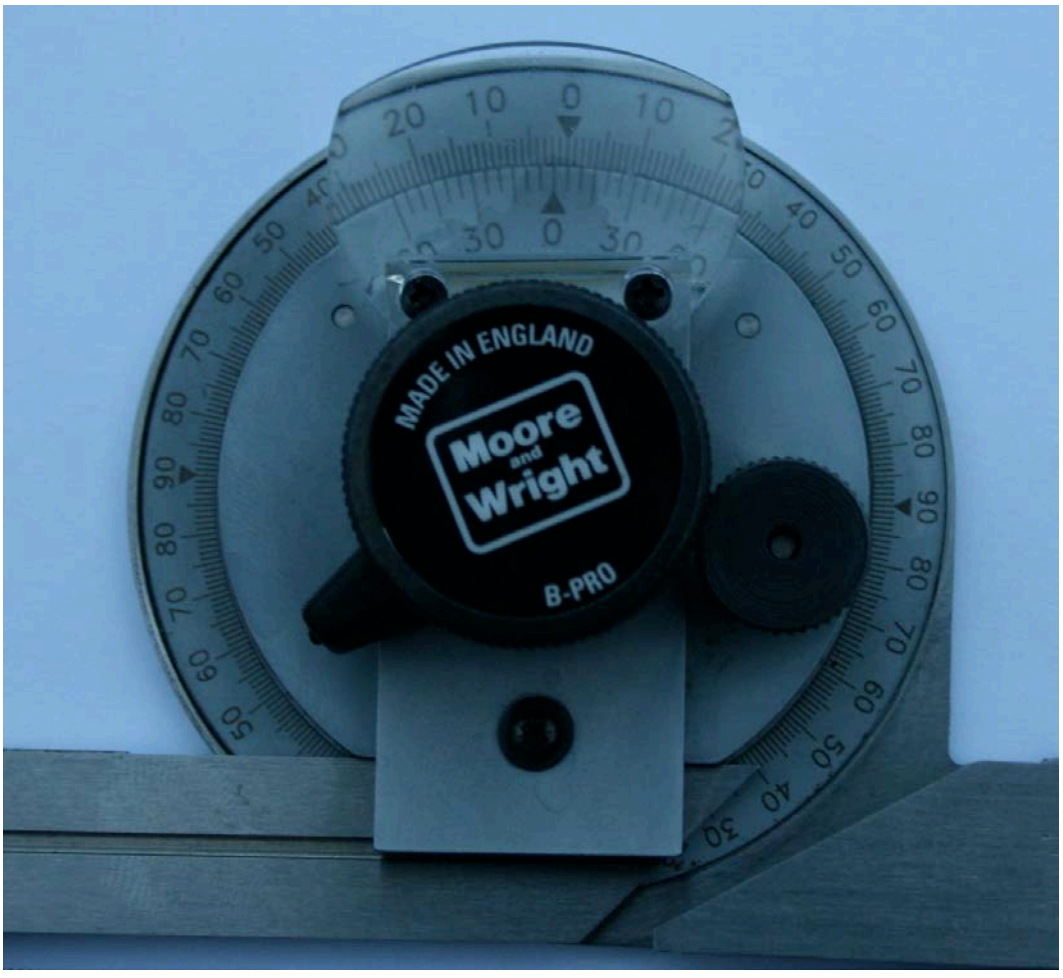


Figure 2:4. A graduated scale plate with magnifying glass for the metal arm bevel protractor
(Moore & Wright; Bowers Metrology Ltd, Bradford, UK)

2.3.1.1 Through range test of the electrogoniometer

With the electrogoniometer attached to the bevel protractor, its validity and accuracy in vitro were measured by moving the bevel protractor in one degree increments from 0 degrees to -60 degrees and from 0 degrees to 60 degrees for 10 repetitions. This process was recorded for ten repetitions to replicate the number of movements performed during position awareness testing of participants in this thesis. The total range tested (120 degrees) exceeds the maximum lumbar flexion and extension movement that the electrogoniometer would be required to move through, when attached to each participant's low back. At each degree increment of the bevel protractor, a recording was made using the electrogoniometer for comparison. Movement of the electrogoniometer was observed for during testing, but no obvious movement was seen. The electrogoniometer was then removed from the arms of the bevel protractor. This in vitro testing of the validity and accuracy of the electrogoniometer was repeated on a separate day, to allow comparison of test-retest data.

2.3.1.2 Signal stability test of the electrogoniometer

The electrogoniometer was fixed to the arms of the bevel protractor as described in 2.3. The signal stability of the testing equipment was recorded for one degree increments from 0 to -10 degrees and at -20, -30, -40, -50 and -60 degrees, and at one degree increments from 0 to 10 degrees and at 20, 30, 40, 50 and 60 degrees. Measurements were taken over a 20 minutes period - at the beginning and after 5 minute intervals - for each angle that was measured. At each of these degrees of the bevel protractor a recording was made using the electrogoniometer for comparison. Twenty minutes was chosen because this was the maximum time that the recording of all the position sense tests would take when testing each participant's low back. The electrogoniometer was then removed from the arms of the bevel protractor. This testing of the in vitro validity and accuracy of the electrogoniometer was repeated on a separate day, to allow comparison of test-retest data.

2.3.2 Data analysis

2.3.2.1 Data processing

Automation of the data collection occurred by the electrogoniometer, using the DataLog system. The data were then exported in ASCII format to a computer workstation. Data were then transferred automatically into a SPSS database. All ICC data analysis was performed using SPSS version 18.0 statistical software (SPSS, Chicago, Illinois, USA). Data were transferred from SPSS to Excel to calculate Bland and Altman tests of agreement. Both Excel and SPSS were chosen for this study and used throughout the thesis, because of their appropriateness and availability through the University and because the researcher was experienced in their use.

2.3.2.2 Test-retest of the electrogoniometer

The data are presented as mean error values for ease of comparison. The error between the angle recorded by the electrogoniometer and the angle recorded by the bevel protractor was calculated in degrees, for each of the 10 tests at each angle measured. The error for each each angle measured, was then calculated as a mean of these 10 error values. A greater error value indicated a greater difference between the angle recorded by the electrogoniometer and the known angle recorded by the calibrated bevel protractor.

In addition, Bland and Altman tests of agreement between measurements that include the mean difference (SD), 2xSD and 95% limits of agreement, and ICC's and the 95% CI for the ICCs are presented where appropriate (Bland & Altman, 1986; Rankin & Stokes, 1998).

For ICCs, the formulae (3,1) was chosen because of the single rater used in this study and future studies in this thesis. Of the other formulae ICC (1,1) has minimal clinical use and can lead to an underestimation of the true correlation, (2,1) is more appropriate when there are multiple raters and (1,*k*), (2,*k*) and (3,*k*) are used when a mean correlation value is calculated either from more than one test or

from more than one rater (Müller & Büttner, 1994; Shrout & Fleiss, 1979):

$$\text{ICC (3,1)} = \frac{\text{subject variability}}{\text{subject variability + random error variability}}$$

2.4 Results

2.4.1 Through range testing of the electrogoniometer

Accuracy of the electrogoniometer when moving the bevel protractor in one degree increments from 0 degrees to -60 degrees and from 0 degrees to 60 degrees for 10 repetitions was found to be accurate within less than 1 degree mean error. This was similar for the data on both day 1 and day 2. Bland and Altman tests revealed mean differences below 0.5 degrees, and that the 95% limits of agreement suggest the true difference was between less than +/- 0.5 degrees (Tables 2:1 and 2:2).

For day 1 mean error of the electrogoniometer, for one degree increments from 0 to -60 degree increments, showed a bias towards positive error values, whereas the 0 to +60 degree increments showed a bias towards negative error values (Figure 2:5). The range and size of the mean error values however, remained similar between tests on day 1 and day 2, with a mean error value at 0.4 degrees or less (Figures 2:5 and 2:6).

ICC (3,1) (Müller et al., 1994; Rankin et al., 1998; Shrout et al., 1979), demonstrated perfect agreement with an ICC value and 95% CI value of 1.00, for one degree increments from 0 degrees to -60 degrees and from 0 degrees to 60 degrees recordings made by the electrogoniometer and bevel protractor on day 1 and day 2. The reasons for this perfect agreement will be discussed.

Table 2:1. Test-retest mean error (SD) in degrees, of the electrogoniometer compared to the bevel protractor, at one degree increments from 0 to -60 degrees – including Bland and Altman tests

	Day 1	Day 2		Day 1	Day 2
Degree	Error Mean (SD)	Error Mean (SD)	Degree	Error Mean (SD)	Error Mean (SD)
0	0.19 (0.21)	-0.07 (0.30)			
-1	0.07 (0.16)	0.07 (0.20)	-31	0.13 (0.25)	-0.09 (0.26)
-2	0.13 (0.40)	-0.09 (0.35)	-32	0.23 (0.29)	-0.16 (0.36)
-3	0.20 (0.27)	-0.14 (0.32)	-33	0.06 (0.31)	-0.03 (0.41)
-4	0.22 (0.19)	-0.18 (0.20)	-34	0.12 (0.27)	0.06 (0.33)
-5	0.24 (0.18)	-0.23 (0.24)	-35	0.06 (0.30)	0.13 (0.23)
-6	0.35 (0.14)	-0.27 (0.37)	-36	0.21 (0.29)	0.04 (0.46)
-7	0.23 (0.21)	-0.14 (0.30)	-37	0.26 (0.17)	0.00 (0.25)
-8	0.35 (0.16)	-0.19 (0.26)	-38	0.16 (0.26)	-0.01 (0.38)
-9	0.35 (0.17)	-0.24 (0.33)	-39	0.30 (0.16)	-0.08 (0.46)
-10	0.32 (0.18)	-0.21 (0.37)	-40	0.16 (0.21)	-0.10 (0.39)
-11	0.31 (0.25)	-0.14 (0.53)	-41	0.35 (0.24)	-0.18 (0.48)
-12	0.12 (0.25)	-0.07 (0.46)	-42	0.28 (0.22)	-0.14 (0.38)
-13	0.22 (0.21)	-0.23 (0.43)	-43	0.18 (0.24)	0.00 (0.32)
-14	0.20 (0.31)	-0.06 (0.43)	-44	0.21 (0.09)	0.00 (0.20)
-15	0.12 (0.27)	0.05 (0.49)	-45	0.15 (0.19)	-0.03 (0.36)
-16	0.16 (0.23)	-0.01 (0.35)	-46	0.14 (0.26)	-0.01 (0.17)
-17	0.38 (0.40)	-0.27 (0.54)	-47	0.13 (0.22)	0.05 (0.32)
-18	0.17 (0.30)	0.01 (0.24)	-48	0.12 (0.29)	-0.03 (0.30)
-19	0.16 (0.23)	0.12 (0.34)	-49	0.12 (0.28)	-0.05 (0.45)
-20	0.10 (0.27)	0.09 (0.36)	-50	0.15 (0.35)	0.12 (0.30)
-21	0.07 (0.30)	0.00 (0.45)	-51	0.09 (0.24)	-0.07 (0.33)
-22	0.05 (0.31)	0.10 (0.47)	-52	0.10 (0.27)	0.00 (0.48)
-23	0.23 (0.28)	0.00 (0.39)	-53	0.13 (0.15)	-0.13 (0.43)
-24	0.22 (0.36)	-0.01 (0.40)	-54	-0.06 (0.41)	0.10 (0.48)
-25	0.20 (0.27)	-0.03 (0.32)	-55	-0.10 (0.27)	0.28 (0.36)
-26	0.11 (0.29)	0.16 (0.39)	-56	0.05 (0.39)	0.03 (0.44)
-27	0.05 (0.31)	0.13 (0.36)	-57	0.10 (0.35)	0.03 (0.51)
-28	0.09 (0.20)	0.10 (0.28)	-58	0.05 (0.44)	-0.07 (0.41)
-29	0.10 (0.29)	0.13 (0.49)	-59	0.01 (0.27)	0.10 (0.41)
-30	0.04 (0.15)	0.10 (0.44)	-60	0.10 (0.29)	0.00 (0.37)
	Bland & Altman				
	Mean difference (SD)			0.16 (0.10)	-0.03 (0.12)
	2xSD			0.20	0.24
	95% limits of agreement			-0.04 to 0.36	-0.27 to 0.21

Table 2:2. Test-retest mean error (SD) in degrees, of the electrogoniometer compared to the bevel protractor, at one degree increments from 0 to 60 degrees – including Bland and Altman tests

	Day 1	Day 2		Day 1	Day 2
Degree	Error Mean (SD)	Error Mean (SD)	Degree	Error Mean (SD)	Error Mean (SD)
0	-0.07 (0.20)	0.13 (0.32)			
1	0.14 (0.14)	0.09 (0.20)	31	-0.22 (0.22)	0.12 (0.39)
2	0.03 (0.25)	0.20 (0.28)	32	-0.25 (0.28)	0.03 (0.40)
3	0.09 (0.25)	0.06 (0.38)	33	-0.01 (0.31)	-0.22 (0.30)
4	0.01 (0.19)	0.07 (0.41)	34	-0.11 (0.30)	-0.05 (0.41)
5	-0.13 (0.18)	0.21 (0.29)	35	-0.05 (0.19)	-0.18 (0.25)
6	-0.11 (0.14)	0.21 (0.22)	36	-0.24 (0.29)	0.07 (0.36)
7	-0.02 (0.23)	0.14 (0.22)	37	-0.32 (0.21)	0.18 (0.36)
8	-0.22 (0.23)	0.17 (0.25)	38	-0.20 (0.27)	-0.05 (0.36)
9	-0.15 (0.19)	0.00 (0.34)	39	-0.13 (0.28)	-0.06 (0.36)
10	-0.22 (0.21)	0.13 (0.35)	40	-0.32 (0.25)	0.00 (0.21)
11	-0.22 (0.21)	0.10 (0.19)	41	-0.21 (0.26)	-0.13 (0.34)
12	-0.27 (0.15)	0.09 (0.31)	42	-0.27 (0.25)	0.13 (0.21)
13	-0.23 (0.17)	0.01 (0.30)	43	-0.08 (0.25)	-0.13 (0.33)
14	-0.27 (0.17)	0.08 (0.31)	44	-0.18 (0.27)	0.10 (0.33)
15	-0.25 (0.17)	0.03 (0.25)	45	-0.21 (0.28)	-0.03 (0.31)
16	-0.26 (0.12)	0.01 (0.26)	46	-0.24 (0.23)	-0.11 (0.28)
17	-0.21 (0.11)	0.10 (0.38)	47	-0.18 (0.20)	-0.16 (0.20)
18	-0.32 (0.21)	0.15 (0.41)	48	-0.29 (0.24)	0.07 (0.37)
19	-0.24 (0.20)	0.06 (0.33)	49	-0.04 (0.21)	-0.14 (0.33)
20	-0.23 (0.19)	-0.03 (0.22)	50	-0.17 (0.27)	-0.04 (0.33)
21	-0.31 (0.27)	0.06 (0.42)	51	-0.15 (0.27)	-0.09 (0.24)
22	-0.13 (0.33)	0.02 (0.35)	52	-0.06 (0.26)	-0.14 (0.28)
23	-0.11 (0.23)	-0.03 (0.13)	53	-0.29 (0.20)	0.18 (0.28)
24	-0.16 (0.27)	0.01 (0.32)	54	-0.26 (0.27)	-0.02 (0.37)
25	-0.28 (0.26)	-0.01 (0.30)	55	-0.23 (0.23)	-0.08 (0.14)
26	-0.24 (0.18)	0.07 (0.22)	56	-0.27 (0.21)	-0.01 (0.30)
27	-0.12 (0.19)	-0.10 (0.32)	57	-0.21 (0.25)	-0.02 (0.33)
28	-0.08 (0.11)	-0.02 (0.32)	58	-0.27 (0.13)	0.07 (0.16)
29	-0.09 (0.20)	-0.25 (0.26)	59	-0.17 (0.24)	-0.06 (0.40)
30	-0.16 (0.25)	-0.07 (0.26)	60	-0.23 (0.20)	0.09 (0.37)
	Bland & Altman				
	Mean difference (SD)			-0.18 (0.10)	0.02 (0.11)
	2xSD			0.21	0.22
	95% limits of agreement			-0.38 to 0.03	-0.20 to 0.23

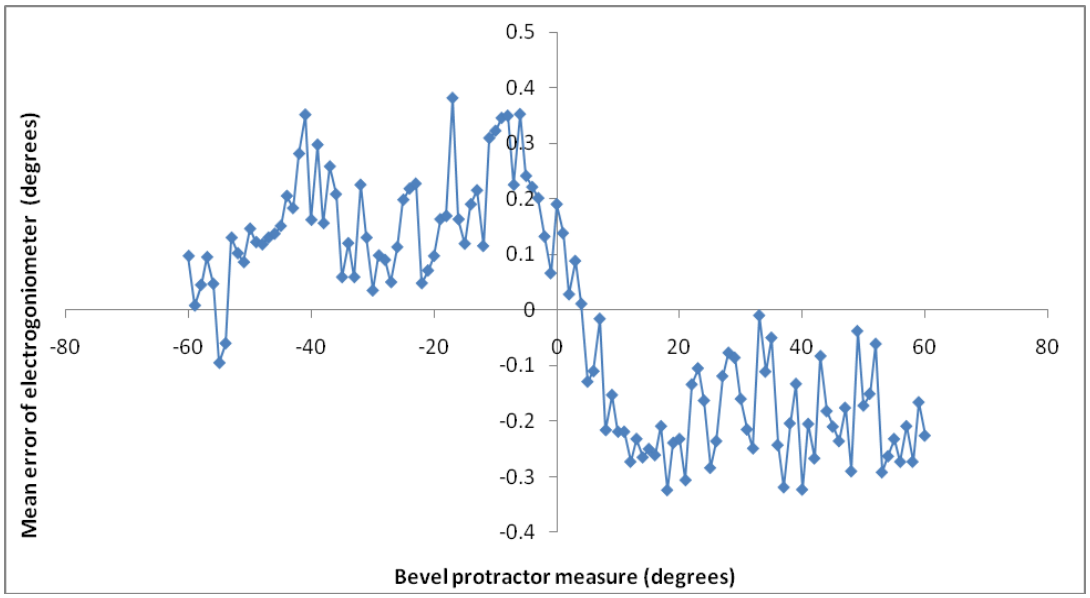


Figure 2:5. Distribution plot from Bland and Altman test showing mean error of the electrogoniometer when compared to the angle recorded by the bevel protractor, at one degree increments from 0 to -/+60 degrees - Day 1

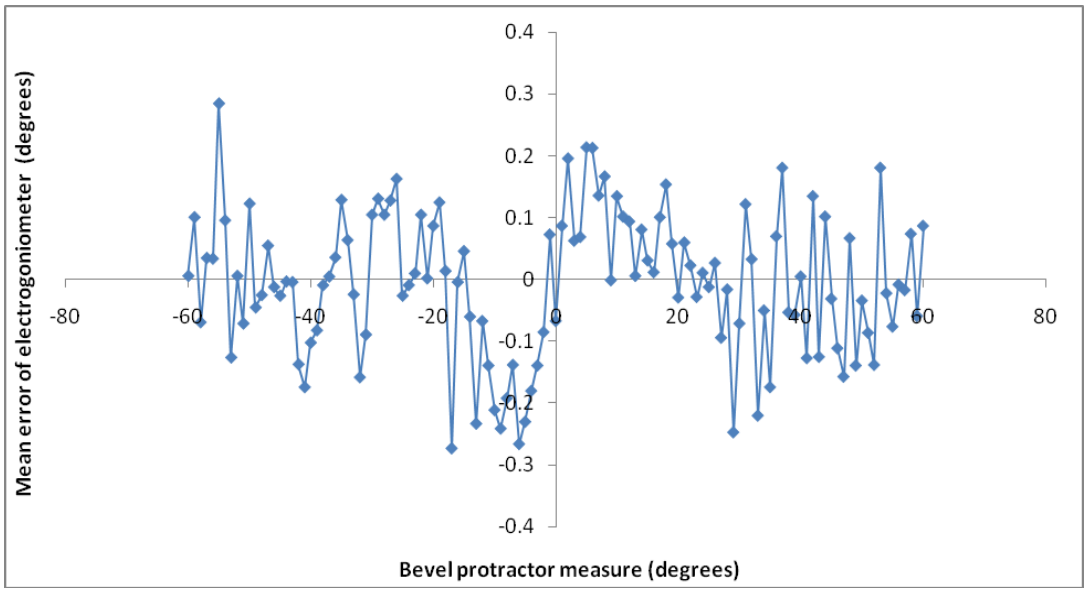


Figure 2:6. Distribution plot from Bland and Altman test showing mean error of the electrogoniometer when compared to the angle recorded by the bevel protractor, at one degree increments from 0 to -/+60 degrees – Day 2

2.4.2 Signal stability testing of the electrogoniometer

Signal stability over 20 minutes at all angles tested (one degree increments from 0 degrees to -10 degrees and at -20, -30, -40, -50 and -60 degrees, and at one degree increments from 0 degrees to 10 degrees and at 20, 30, 40, 50 and 60 degrees), was accurate to less than 1 degree mean error for both test-retest data (Tables 2:3 and 2:4). This was similar for both day 1 and day 2 data. Bland and Altman tests revealed mean differences below 0.5 degrees, and that the 95% limits of agreement suggest the true difference was between less than +/- 0.6 degrees.

Figures 2:7 and 2:8 suggest that the signal stability mean error of the electrogoniometer for 0 to -60 degree increments showed a bias towards negative error values, whereas the 0 to +60 degree increments showed a bias towards positive error values. This is discussed in section 2.5. The range and size of the mean error values however, remained similar between 0 to -60 and 0 to 60 degree increments on both day 1 and day 2 tests, at less than 0.5 degrees (Figures 2:7 and 2:8).

ICC (3,1) (Müller et al., 1994; Rankin et al., 1998; Shrout et al., 1979), demonstrated perfect agreement with an ICC value and 95% CI value of 1.00, for one degree increments from 0 degrees to -60 degrees and from 0 degrees to 60 degrees recordings made by the electrogoniometer and bevel protractor on day 1 and day 2. The reasons for this perfect agreement will be discussed in section 2.5.

Table 2:3. Test-retest mean error (SD) in degrees, of the electrogoniometer compared to the bevel protractor, for signal stability from 0 to -60 degrees – including Bland and Altman tests

	Day 1	Day 2
Degrees	**Error Mean (SD)**	**Error Mean (SD)**
0	-0.06 (0.28)	-0.08 (0.17)
-1	0.10 (0.29)	-0.37 (0.29)
-2	-0.05 (0.22)	0.02 (0.30)
-3	-0.07 (0.28)	-0.11 (0.25)
-4	0.01 (0.28)	0.08 (0.39)
-5	0.13 (0.38)	-0.14 (0.24)
-6	-0.16 (0.24)	-0.29 (0.20)
-7	-0.24 (0.28)	-0.33 (0.20)
-8	-0.22 (0.22)	-0.10 (0.18)
-9	-0.02 (0.24)	-0.20 (0.18)
-10	0.00 (0.20)	0.11 (0.25)
-20	-0.18 (0.21)	0.00 (0.23)
-30	-0.35 (0.19)	-0.15 (0.33)
-40	-0.41 (0.13)	-0.16 (0.19)
-50	-0.48 (0.14)	-0.43 (0.26)
-60	-0.44 (0.11)	-0.23 (0.31)
Bland & Altman		
Mean difference (SD)	-0.16 (0.20)	-0.15 (0.16)
2xSD	0.39	0.32
95% limits of agreement	-0.55 to 0.23	-0.48 to 0.17

Table 2:4. Test-retest mean error (SD) in degrees, of the electrogoniometer compared to the bevel protractor, for signal stability from 0 to 60 degrees – including Bland and Altman tests

	Day 1	Day 2
Degrees	**Error Mean (SD)**	**Error Mean (SD)**
0	-0.06 (0.28)	-0.08 (0.17)
1	-0.04 (0.34)	0.03 (0.32)
2	0.14 (0.40)	0.03 (0.19)
3	-0.19 (0.43)	0.13 (0.16)
4	0.23 (0.19)	0.03 (0.13)
5	0.18 (0.25)	0.14 (0.23)
6	-0.04 (0.24)	0.01 (0.25)
7	-0.02 (0.24)	0.00 (0.14)
8	0.21 (0.34)	0.10 (0.15)
9	0.14 (0.24)	-0.27 (0.23)
10	0.04 (0.23)	-0.07 (0.19)
20	0.35 (0.19)	-0.04 (0.32)
30	0.16 (0.26)	0.09 (0.36)
40	0.47 (0.12)	-0.13 (0.25)
50	0.49 (0.21)	0.24 (0.31)
60	0.45 (0.14)	0.07 (0.42)
Bland & Altman		
Mean difference (SD)	0.16 (0.21)	0.02 (0.12)
2xSD	0.42	0.24
95% limits of agreement	-0.25 to 0.57	-0.22 to 0.26

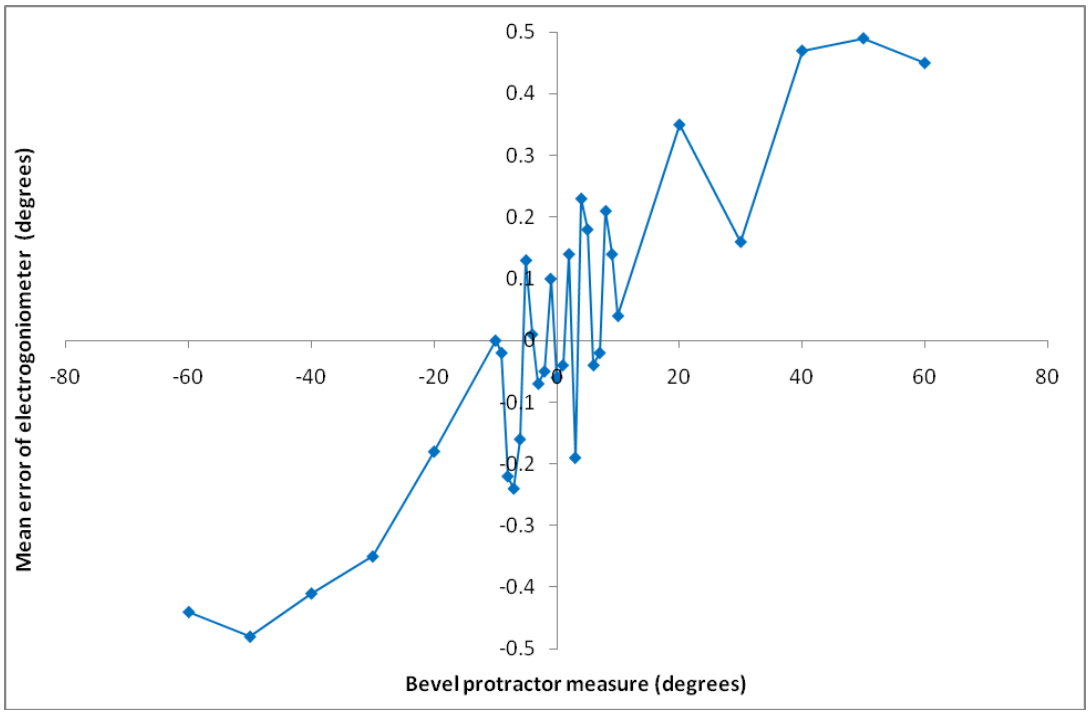


Figure 2:7. Distribution plot from Bland and Altman test showing signal stability mean error of the electrogoniometer when compared to the angle recorded by the bevel protractor - Day 1

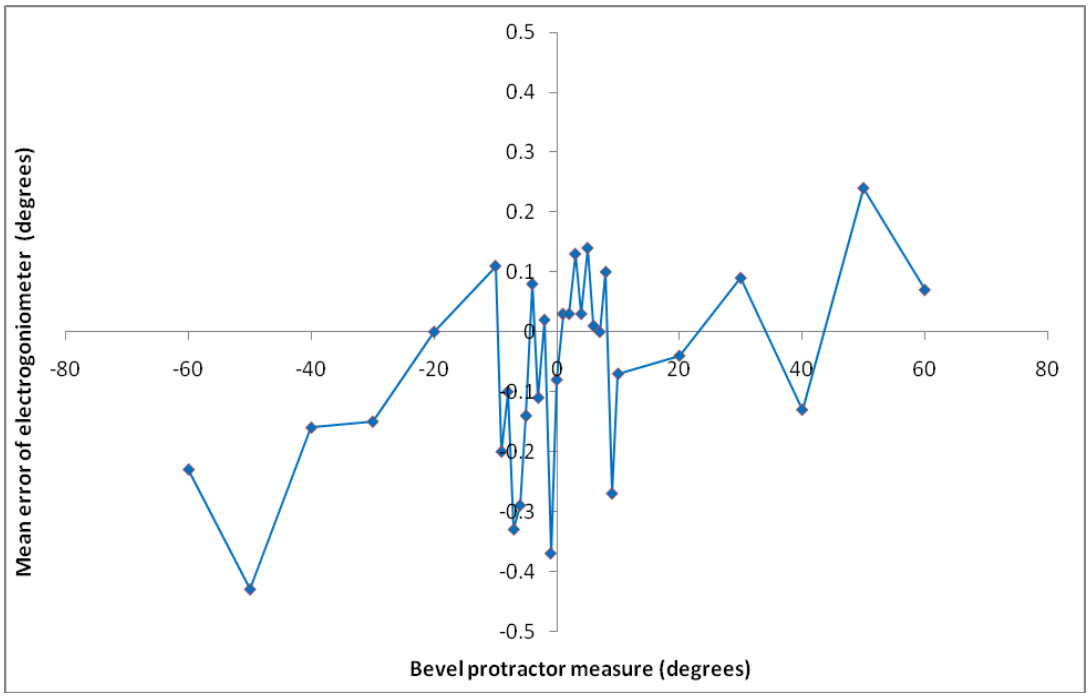


Figure 2:8. Distribution plot from Bland and Altman test showing signal stability mean error of the electrogoniometer when compared to the angle recorded by the bevel protractor – Day 2

2.5 Discussion

2.5.1 Test-retest reliability of the electrogoniometer in vitro

This study found the electrogoniometer to be a valid and reliable measure of degrees during movement in the sagittal plane, when compared to measurements using a calibrated, highly accurate, bevel protractor. The electrogoniometer was tested at single incremental angles between -60 to 0 to +60 degrees of sagittal movement. Stability of the electrogoniometer measure was also confirmed at different angles between the same ranges of movement.

The electrogoniometer was accurate to within 1 degree mean error for both through range and stability testing, on both days. The results suggest that the electrogoniometer is unaffected by environmental differences and its dismantling, reassembly and reapplication between the test days. This measurement error is small enough to recommend the electrogoniometer could be used to investigate and potentially detect, clinically meaningful differences in means of 2 degrees error in position sense of the low back (Kiefer, Shirazi-Adl, & Parnianpour, 1997), between people with and without LBP. It is acknowledged however, that the results presented in this chapter relate to the accuracy and validity of the electrogoniometer in vitro. Results of in vivo test-retest reliability are presented in Chapters 3, 4 and 5.

These in vitro results are similar to those of Rowe et al., (2001) who reported that during in vitro testing, the electrogoniometer was accurate to within 1 to 2 degrees across ranges up to -120 to +120 degrees, or between 1% and 1.5% of the measuring range. Over the range of +/-60 degrees used in this study, a measurement error between 0.6 to 0.90 degrees may therefore be expected. This level of measurement error is similar to the Bland and Altman 95% limits of agreement (Tables 2:1 to 2:4). These small limits of agreement make

us confident the electrogoniometer can accurately measure angular movement over the range of +/-60 degrees (total of 120 degrees). Bland and Altman tests of agreement showed that the mean differences between measurements were close to zero and the SDs of the differences were small. This suggests “good” agreement between the measurements of the electrogoniometer and the calibrated bevel protractor (Bland et al., 1986; Rankin et al., 1998).

On day 1, the through range mean error recordings of the electrogoniometer when compared to the angle recorded by the bevel protractor were (1) positive when testing from 0 to -60 degrees, and (2) negative when testing from 0 to 60 degrees (Figure 2:5). On day 2, the mean error recordings were closer to zero and the values were both positive and negative when testing either 0 to -60 degrees, or 0 to 60 degrees (Figure 2:6). This small difference between day 1 and day 2 recordings may be due a slight error in lining up the scale and pointer on the bevel protractor when the electrogoniometer recording is zeroed.

The signal stability mean error recordings of the electrogoniometer, compared to the angle recorded by the bevel protractor, tended to show a bias towards a small negative value when testing from 0 to -60 degrees, and a small positive value when testing 0 to 60 degrees, for both day 1 and day 2 (Figures 2:7 and 2:8). This bias may also be due to a slight difference in the positioning of the scale and pointer on the bevel protractor when the electrogoniometer recording is zeroed.

Importantly, any bias towards positive or negative mean error recordings by the electrogoniometer did not alter the range of the mean errors. They remained similar and relatively small (Figures 2:5 and 2:6; Figures 2:7 and 2:8). The ranges for the 95% limits of agreement were similar for both days, and for both through range and signal stability testing.

Studies of reliability recommend ICCs, and Bland and Altman tests of agreement are presented. Both are considered to be appropriate when there are two repeated measures (Rankin et al., 1998). ICC formulae (3,1) was used in this study, because the rater i.e. a single investigator,

was the only one of interest. This rater was therefore fixed and the reliability will reflect the accuracy of this rater only and cannot be generalised to how reliably other raters may perform. The decision to choose ICC (3,1) was also because testing in the remaining thesis was performed by the same individual who did the reliability testing, and consequently ICC (3,1) was the appropriate choice (Müller et al., 1994; Rankin et al., 1998; Shrout et al., 1979).

The results of ICCs in this study showed perfect agreement, however this can be a reflection of the wide range of data points on the measurement scale. The greater the range of data points on a scale, the better the ICC will be (Müller et al., 1994). In this study the data points are +/-60 degrees, therefore with such a large range, the ICC results are predictably very high. This limitation of ICCs should not detract from the small mean difference found between the measurements of the electrogoniometer and bevel protractor, for both through range and stability testing, on both days.

The electrogoniometer was tested through a total of 120 degrees of range (+/- 60 degrees). This was to ensure it was tested over greater range than the total amount of spinal flexion and extension that may occur when assessing people with and without LBP. Studies have reported a mean total sagittal range range of 40 degrees in people with and without LBP (Twomey & Taylor, 2000), 44.63 degrees in a cadaveric study (Taylor & Twomey, 1980; Twomey, 1979), 68 degrees in male participants with no LBP (Pearcy, Portek, & Shepherd, 1984) and 74 degrees in women, although there was no confirmation of any LBP (Trudelle-Jackson, Fleisher, Borman, Morrow, & Frierson, 2010). Comparing study findings on range of movement is difficult because of differences in measurement devices, the age range of participants, the spinal levels measured and whether the participant was measured in standing, sitting or lying (See Section 5.7.3). In the study in Chapter 6, the mean total sagittal range in the low back from L1 to S1 in sitting for all participants, was 39.29 degrees. There is uncertainty whether the electrogoniometer will show similar validity and reliability when measuring greater than 120 degrees (+/- 60 degrees), but this is

irrelevant when investigating movement of the low back where the range is considerably less.

In this study, a similar observation was made to that of Rowe et al., (2001), in that errors can become substantial if the electrogoniometer moves excessively in another plane at the same time e.g. if side flexion or rotation movement occurs during sagittal movement. These errors increase with greater flexion/extension range (see section 2.1). This “crosstalk” (Jonsson et al., 2001), would effect the validity and reliability of the electrogoniometer and was therefore avoided. It was consequently also avoided during testing on people with and without LBP in this thesis. It is acknowledged however, this is a simplification of spinal movement as the spine moves in more than one plane. To minimise any potential for measurement error, it was considered important that movements in the sagittal plane were investigated, without the addition of movements in other planes. This was to ensure greater confidence in the results found in the studies in this thesis.

Other measuring equipment was considered before deciding on use of the electrogoniometer for the studies in this thesis. A motion analysis system was considered as an alternative measuring device, but the portability, availability and ease of use of the electrogoniometer were important practical factors in deciding on its choice (Rowe et al., 2001). The 3-space Fastrak was also considered because of its similar portability (Lam et al., 1999; O'Sullivan et al., 2003), but its method of set up (Dolan et al., 2006) was considered a disadvantage in comparison to electrogoniometry. In addition, members of the research team and other local contacts had experience of using the electrogoniometer on clinical populations (including on the low back), which it was felt would be very useful resource. Finally, Biometrics Ltd. who manufactured the electrogoniometer, made regular site visits to the University and the technical support over the phone, plus the ability to visit their factory for advice, were considered an important resource.

2.5.2 Limitations of the study

The results of this study only relate to flexion/extension movement. As explained in sections 2.1. and 2.5.1, this was to avoid the potential for measurement error that can occur if the electrogoniometer moves excessively in another plane at the same time. It was consequently only used in a flexion/extension plane in Chapters 3, 4 and 5.

The results of this study only relate to the use of the back electrogoniometer (flexible M180B electrogoniometer, Biometrics Ltd, Gwent, UK), and its use over a range of 0 to +/- 60 degrees. This range however, was considered appropriate as it is in excess of the range of low back movement tested in Chapters, 3, 4 and 5. In addition, the results only reflect the specific electrogoniometer used in this study. This specific electrogoniometer was used throughout the studies in this thesis. Whether the results would be similar for other back electrogoniometers is unknown, although others have found the results to be similar when testing a number of different M180 electrogoniometers used to measure other joints (Rowe et al., 2001).

The results of signal stability testing for specific angles are in relation to a limited time of 20 minutes. This time period however, is the maximum time the data collection will take in Chapters 3, 4 and 5.

Testing was repeated on a separate day to investigate the affect of dismantling, re-assembly and re-application of the equipment. It is uncertain whether the results would be similar if testing was repeated on more than two separate days, but there is no reason to suspect that the results would be any different. Testing on two separate days also reflects the number of test days presented in Chapters 3, 4, and 5.

It is acknowledged that the electrogoniometer needs to be carefully handled to avoid damage. The accuracy data reported are the results obtained at the end of all testing for all studies in this thesis. This demonstrates that if handled carefully the equipment remains accurate even after significant use.

2.5.3 Implications of the research

As far as could be determined, this study was the first to investigate the accuracy, stability and through range test-retest reliability of the back electrogoniometer against a calibrated device with known angular measures.

The results in Chapter 2 demonstrated that the electrogoniometer equipment was accurate to within a range of 0 to 0.40 degrees of mean error, for through range testing, between +/- 60 degrees, and between 0 to 0.5 degrees of mean error for signal stability testing between +/- 60 degrees. This was considered an acceptable level of accuracy for it to be used to investigate position sense in people with and without LBP in Chapters 3, 4 and 5.

The results only reflect the accuracy of the electrogoniometer in the sagittal plane. Testing in Chapters 3, 4 and 5 is therefore restricted to testing position sense in this single plane. It is acknowledged however, that the spine moves in more than a single plane.

The results only relate to a single rater (the researcher). The researcher is therefore the only investigator to use the electrogoniometer in the studies in Chapters 3, 4 and 5.

In addition to been highly accurate, the electrogoniometer is easy to use, takes little time to set-up and is inexpensive. Also, valuable support was easily available from members of the research team and the manufacturer. It was therefore considered an appropriate choice for use in the studies in Chapters 3, 4 and 5.

2.6 Summary of findings

- *When compared in vitro to a very accurately calibrated bevel protractor*
- the electrogoniometer is a valid and reliable measure of single incremental angles between -60 to 0 to +60 degrees of movement
- the measures recorded by the electrogoniometer were stable at different angles between -60 to 0 to +60 degrees of movement
- the electrogoniometer is unaffected by its dismantling, reassembly and reapplication between the two test days.

3 POSITION SENSE IN THE LOW BACK BEFORE AND AFTER WORK

3.1 Background

Of the studies that have looked at spinal proprioception (Maffey-Ward et al., 1996; McGlashen, Ashton-Miller, Green, & Schultz, 1991; Taylor & McCloskey, 1990), some report position awareness deficits in patients with LBP compared to NLBP participants (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003), while others have found no differences (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000).

Many of these studies however, have methodological limitations which undermine confidence in their conclusions. These limitations included small numbers of participants (Descarreaux et al., 2005; O'Sullivan et al., 2003), with studies rarely commenting on sample size calculation when reporting their findings (Brumagne et al., 2000; Descarreaux et al., 2005; Gill et al., 1998; Lee, Cholewicki, Reeves, & Zazulak, 2010; O'Sullivan et al., 2003; Taimela et al., 1999). This creates uncertainty as to whether studies were underpowered and risking a type II “false negative” error, or an increased probability of a type I “false positive” error if associated with multiple-testing. Others had inappropriate NLBP control groups containing participants who could have had recent LBP (Gill et al., 1998), whereas if more stringent entry criteria for NLBP population had been adopted, it is unknown whether smaller errors in position sense might have occurred in these participants and potentially greater differences found compared to people experiencing LBP. Additionally, studies commonly tested position sense only in standing (Newcomer et al., 2000; Swinkels et al., 2000) or in non-functional positions like four point kneeling (Gill et al., 1998), so how the findings relate to postures such as sitting, remains unclear.

To date, no study has investigated the effect of the working day on proprioceptive acuity, by testing people before and after a shift of work.

It is possible that exposure to factors associated with the working day, that include prolonged flexed sitting postures (Dolan et al., 2006), vibration (Brumagne et al., 2000; Hurley et al., 2000) and prolonged trunk muscle activity (Hurley et al., 2000; Taimela et al., 1999); could potentially decrease proprioceptive acuity.

At work, exposure to regular, prolonged sitting may have led to disuse in the trunk muscles (Moffroid, Haugh, Haig, Henry, & Pope, 1993; O'Sullivan et al., 2006). There may also be exposure to repetitive occupational-related activities (e.g. lifting, vibration and bending), which may have caused or aggravated LBP (Bovenzi et al., 1992; Keyserling, 2000; Kumar, 1990). Poor posture in sitting or during manual work, stresses innervated tissues and causes abnormal repetitive habitual loading (Panjabi, 2006). In addition, people who perform more physical work could be exposed to prolonged trunk muscle activity which could test the endurance capabilities of these muscles. If trunk muscles are subsequently dysfunctional due to work-related postures or activity, any associated decrease in muscle spindle sensitivity might impair people's low back position sense and the body's ability to detect and react to harmful abnormal spinal movement and loading.

Furthermore, it is reported that trunk extensor endurance, and trunk flexor endurance and strength are reduced in LBP (Biering-Sørensen, 1984; Luoto et al., 1995; Suzuki et al., 1983). These may be risk factors for on-going pain (Biering-Sørensen, 1984; Mannion et al., 1997a) as people with LBP will be less able to rapidly develop trunk muscle force, in response to sudden loads (Wilder et al., 1996), thus making the spine vulnerable to injury and pain. Any delays in muscle responses due to LBP could affect people's ability to make appropriate responses to normal or abnormal loading during static and dynamic postures. This suggests that decreased or delayed awareness of spinal posture and movement may be more likely in people with LBP. Consequently, greater error in low back position sense may be found when testing people with LBP.

Although studies have found that prolonged flexed sitting postures impair spinal position awareness in people without LBP (Dolan et al., 2006), it is yet to be determined, whether a similar effect occurs in people with LBP and whether any deficits are greater than found in people without LBP. It is also yet to be determined, whether any effects on spinal position sense are more likely to occur in a specific population of workers, exposed to particular occupational factors e.g. sedentary workers, manual workers or drivers. In addition, it is also unknown whether any occupation related changes in spinal position sense are greater in people with LBP. The consequence of impairment in spinal positions awareness is that it could lead to poor responses to sudden loading and movement, and potential injury and pain (Panjabi, 2006; Wilder et al., 1996).

Aim:

The primary aim of this study was to investigate whether people with recurrent non-specific low back pain can estimate low back position sense as accurately as people who have never reported back pain, before and after exposure to their normal daily work routine.

A secondary aim was to investigate whether people with recurrent non-specific low back pain from a specific occupational group, can estimate low back position sense as accurately as people who have never reported back pain from the same occupational group, before and after their normal daily work routine.

The study also investigated the test-retest reliability of data for each position awareness tests.

3.2 Null hypothesis

3.2.1 Primary null hypothesis

1. Before a shift of work there is no difference in low back position sense between people with recurrent non-specific low back pain and people who have never reported low back pain.

2. After a shift of work there is no difference in low back position sense between people with recurrent non-specific low back pain and people who have never reported low back pain.

3.2.2 Secondary null hypothesis

1. Before a shift of work there is no difference in low back position sense between people with recurrent non-specific low back pain from a specific occupational group (sedentary, drivers and manual workers) and people who have never reported low back pain from the same occupational group.

2. After a shift of work there is no difference in low back position sense between people with recurrent non-specific low back pain from a specific occupational group (sedentary, drivers and manual workers) and people who have never reported low back pain from the same occupational group.

3.3 Methodology

As similar to previous studies, a quantitative approach was used to compare position awareness between people with and without LBP, with reposition error the quantitative value for comparison (Gill et al., 1998; Newcomer et al., 2000; O'Sullivan et al., 2003). In this research, reposition error was measured in degrees using a flexible M180B electrogoniometer (Biometrics Ltd, Gwent, UK) (Figure 2:1).

3.4 Methods

3.4.1 Design

A cross-sectional study design was chosen to observe position awareness at a point in time in a population with and without LBP. As measurement of position awareness was not carried out before and after the onset of LBP, the design cannot prove a cause-effect relationship. Instead, the findings would be used to develop hypotheses to be investigated in future studies.

3.4.2 Ethical approval and research governance

Ethical approval was given by the Southampton and South West Hampshire Local Research Ethics Committee (LREC number: 056/01/t). A copy of the approval letter is shown in Appendix 3:1. The University of Southampton acted as sponsor for the research.

3.4.3 Participant profiles and entry criteria

People with and without recurrent non-specific LBP were recruited (for details on recruitment see 3.4.5) from each of the following occupational groups;

- sedentary - participants who predominately sat during a 7-hour day;
- driving - participants who predominately drove during a 7-hour day;
- manual - participants who predominately did manual work during a 7-hour day.

Sedentary workers and drivers were chosen as participants because exposure to regular, prolonged sitting may cause trunk muscle disuse (Moffroid et al., 1993; O'Sullivan et al., 2006). Drivers and manual workers were chosen because of their potential exposure to repetitive lifting, vibration and bending, which can cause or aggravate LBP (Bovenzi et al., 1992; Keyserling, 2000; Kumar, 1990). All these occupational groups may be exposed to poor posture during their work, that stresses pain-sensitive structures and cause abnormal repetitive loading (Panjabi, 2006). In addition manual workers were also chosen because their trunk muscles could be exposed to prolonged activity that affects trunk muscle endurance. Whether in sedentary, driving or manual occupations any trunk muscle dysfunction, associated decrease in muscle spindle sensitivity, repetitive end range loading or pain, might impair people's low back position sense.

Information on occupation and adherence to the entry criteria below, were determined by the researcher over the telephone with participants, prior to their inclusion in the study, and then later reconfirmed if they attended for testing.

3.4.3.1 Participants with low back pain

- Participants aged between 18-60 years. An upper age limit of 60 years was chosen to minimise the possibility of participants having age-related decreases in position sense, which occur from the mid to late sixties (Hurley et al., 1998a; Pai et al., 1997).
- Participants with LBP had recurrent non-specific LBP defined as:
    - pain between the lowest ribs and gluteal folds (Smedley et al., 1997)
    - with or without referral into the legs
    - LBP not attributable to a recognisable, known specific pathology i.e. several structures may contribute to the LBP, such as the joints, discs and connective tissue (Airaksinen et al., 2006; NICE, 2009; van Tulder et al., 2006)
    - a painful episode in the previous 3 months lasting greater than 24 hours (Smedley et al., 1997)
    - previous history of at least one other episode of LBP (Little et al., 2008) lasting greater than 24 hours
    - and at least one episode in the past that has necessitated medical advice on at least one occasion.

These criteria aimed to ensure participants had experienced LBP of sufficient seriousness that it was potentially more likely to affect sensorimotor function than e.g. transient LBP lasting 1 to 2 hours and occurring 6 months previously.

3.4.3.2 Participants without low back pain

Participants aged 18-60 years, who had not reported even minor LBP within the last 12 months, with no history of LBP lasting longer than 24 hours that had necessitated a period off work, bed rest or health care attention and intervention of any sort, and no injuries to their lower back. These criteria were to minimise the possibility of sensorimotor function being affected due to age or previous minor episodes of LBP.

3.4.3.3 Exclusion criteria

Participants (LBP and NLBP) were excluded if they demonstrated any of the following:

- inability to perform the movements required for the proprioceptive tests.
- severe LBP on the day of testing - a score of greater than 8 out of 10 on the pain questionnaire. This cut-off point was a pragmatic decision based on clinical experience. If pain was too high, it was felt participants might not be able to complete the test movements and their pain could be aggravated, leading to potential concerns from the Local Research Ethics Committee. Extreme levels of pain were therefore avoided, in an attempt to decrease the likelihood of this occurring.
- inability to complete the questionnaires e.g. due to language or understanding of the questions even after explanation by the researcher.
- unstable co-existing rheumatalogical, cardiovascular, respiratory, neurological, psychiatric or psychological disorders or medical conditions that might affect balance and sensorimotor function such as Ménière's disease, vertigo, vestibular disturbances. The aim was to mitigate the possibility of participants being unable to perform or complete the testing, or to have medical conditions that may affect sensorimotor function.
- use of systemic steroids or anticoagulants. Although unlikely, this was felt necessary to minimise the potential for pain or soreness as a result of performing the test movements.
- surgery to the back, pelvis or head as these had the potential to affect sensorimotor function.
- progressive nerve root signs and symptoms; cauda equina symptoms; non-mechanical pain (a pain not affected by movement or position). These symptoms suggested more severe pathology requiring specific medical assessment or treatment and could have been easily aggravated by testing.

- a history of pain or injury in both elbows. In addition to testing position sense in the low back, the dominant elbow was also tested in all participants, to investigate for the possibility that any proprioceptive deficits in the low back were due to a global problem of sensory deficits or central processing (see section 3.4.6.3 Reposition error in the elbow). The choice of the elbow was pragmatic, as it is easy to view and measure. In addition, alterations in low back sensorimotor function are unlikely to affect upper limb sensorimotor function, but could affect this in the lower limb, for example if measuring the knee joint. If there was a history of pain or injury in this elbow the non-dominant side was tested.

3.4.4 Sample size

For the primary comparison of proprioceptive acuity between all workers with and without LBP, a sample size of 20 participants with LBP and 20 participants without LBP was calculated to have 90% power to detect a difference in means of 2 degrees error in position sense (Kiefer et al., 1997) assuming a standard deviation of 1.88 degrees (Swinkels et al., 2000) using a two group t-test with a 0.05 (5%) two-sided significance level (Lemeshow, Hosmer, Klar, & Lwanga, 1992).

Similarly, for sub-group analyses, 20 participants with LBP and 20 with non-low back pain (NLBP) were required in each of the three occupational groups.

It was therefore planned to recruit 120 participants in total.

3.4.5 Recruitment

Recruitment and testing took place between November 2001 and July 2003. Participants with and without LBP were invited by the researcher to participate by letters sent to local employers, posters in the workplace and adverts placed in the local evening press and weekly free newspapers (Appendices 3:2, 3:3, 3:4). Interested participants responding from the workplace or adverts were sent the information letter by the researcher via email, fax or post (Appendix 3:5).

All potential participants were given the opportunity to read the information sheet and discuss it with relatives, friends and the researcher before participating in the study. All interested participants were telephoned by the researcher and asked to confirm their eligibility including their occupation status prior to participation (Appendix 3:6). Eligibility was reconfirmed by the researcher when the participants attended for research testing at a dedicated small research room (3 metres x 3 metres; with a desk, chair and up and down couch), at the School of Health Professions and Rehabilitation Sciences (was subsequently named School of Health Sciences and now Faculty of Health Sciences), University of Southampton. It was explained by the researcher that participation in the research project was entirely voluntary, and that they could withdraw from the study at any time without giving reason and without prejudice.

To facilitate recruitment and ensure participants were not financially disadvantaged, their time / travel expenses were reimbursed at £25 per visit a predetermined level agreed by the Ethics Committee.

3.4.6 Data collection procedure

The participants and methods used in this study were the same for both the before-work and after-work testing. The after-work tests were performed on a different day to the before-work test, as participants were required to work a full day prior to testing and this would not have been possible if tested earlier in the same day. Furthermore,

testing on another day was necessary to minimise any potential learning effect and to avoid the possibility repeated testing on the same day could risk aggravating LBP symptoms.

In an attempt to minimise possible diurnal variations between participants, all testing before-work took place at similar times. In addition, all testing after-work also took place at similar times. This was to minimise the possible effect of changes in range of low back movement due to time (Dvorák, Vajda, Grob, & Panjabi, 1995) (see section 5.6). Testing before-work took place between 07.30 and 09.30 and after-work it took place between 16.00 and 19.00.

3.4.6.1 Clinical examination

Each participant was telephoned by the researcher and demographic details obtained including: details of occupation; age; weight; height; plus their medical history and back problems, e.g. history of onset, number of recurrent episodes per year, average duration of symptoms and previous management (Appendix 3:6). Eligibility for entering the study was established by the researcher when participants attended for testing (both before and after-work), to ensure no participant changed from having no LBP to now reporting LBP. Written consent was attained prior to participation and was taken by the researcher when the participant first attended for testing (Appendix 3:7).

3.4.6.2 Self-administered questionnaires

Participants then completed self-administered questionnaires related to their back pain (Appendices 3:8 & 3:9), prior to testing their reposition awareness. In addition, participants without LBP were required to complete these questionnaires to ensure they had remained asymptomatic.

Disability

Disability was assessed using the modified Roland Disability Questionnaire (RDQ) which is purported to be a valid, reliable, self-

completed questionnaire (Patrick et al., 1995) (Appendix 3:8). Determining a level of self-reported disability enabled further investigation into whether there is an association between disability and errors in position sense. This questionnaire was chosen because it is short, easily understood by patients, simple to use, includes reference to leg pain, as well as LBP, and is recommended for assessing physical function in people with LBP (Patrick et al., 1995; Roland & Fairbank, 2000) and particularly in general populations with mild to moderate disability similar to the LBP participants recruited in this research (Bombardier, 2000; Roland et al., 2000).

The modified RDQ has 23 questions, each scoring 1 point if ticked and the higher the score, the greater the disability due to LBP. It is difficult to compare validity, responsiveness and reliability with other measures between studies because of the different populations of people with LBP, design of studies and how the measures are recorded (Kopec, 2000). Within study comparisons however, are possible. Patrick et al., (1995), compared this modified-RDQ with the Medical Outcomes Study 36-item Short-Form Health Survey (SF-36), and disability (bed rest, restricted activity days, days lost at work). The authors reported high internal consistency which is an index of reliability (Cronbach's alpha 0.90) and responsiveness or sensitivity to clinical change (Guyatt responsiveness 1.90), moderate reproducibility at 3 months, high correlation with clinical findings or symptoms and disability days, suggesting a high degree of construct validity (Patrick et al., 1995).

A valid measure is one that is measuring what it was intended to, allowing accurate inferences to be made about a person e.g. with LBP. To validate a measure of disability related to LBP, is to determine the degree of confidence that can be made on the inferences about disability in people with LBP, based on their scores when completing the measure. The inferences, in this case about disability in LBP, are derived from a construct i.e. a theoretical concept. Construct validation is an ongoing process of learning more about a theoretical concept(s) and how they relate, developing scales to measure these, and testing

how they relate to observable manifestations of disability in LBP. It is therefore an assessment of both the theoretical concepts and the measure itself. A person with LBP who has a high score and labelled as having a high level of disability related to LBP on a new measure, would be expected to have a high score and high level of disability related to LBP when completing the established measure (Streiner et al., 2008). Conventionally, criterion validation is the correlation of a scale, ideally to a "gold standard" measure. This process is known as concurrent validation e.g. a study to correlate the new scale with the criterion measure, with both measures to be completed at the same time. There is however no "gold standard" for measuring disability in populations with LBP (Hicks & Manal, 2009; Stratford, Binkley, Riddle, & Guyatt, 1998).

Pain

The level of LBP was assessed using the short-form McGill Pain Questionnaire (SF-MPQ), to investigate any association between pain and proprioceptive deficits (Appendix 3:9). This questionnaire was chosen because it can provide quantitative measures of pain to be used statistically, and is quick and easy to complete (Melzack, 1987). It is reported that it has high correlation to the standard long-form McGill Pain Questionnaire (LF-MPQ) (correlation range 0.32 to 0.93 for musculoskeletal pain, with 12 out of 14 values ›0.61) (Melzack, 1987) which has strong psychometric properties (Grimmer-Somers, Vipond, Kumar, & Hall, 2009; Melzack, 1975).

The SF-MPQ consists of three parts, with the first a Pain Rating Index consisting of 15 sensory and affective pain descriptors ranked from none (scoring 0), mild (scoring 1), moderate (scoring 2) and severe (scoring 3). The second part is a 100mm long visual analogue scale from "no pain" to "worst possible pain". Finally the Present Pain Index (PPI) from no pain (scoring 0), mild (scoring 1), discomforting (scoring 2), distressing (scoring 3), horrible (scoring 4) and excruciating (scoring 5). The higher the score in these three parts the greater the level of intensity of LBP. It has been widely used in pain research including LBP and is considered a valid tool that demonstrates internal

consistency (correlation 0.78 for the sensory dimensions; 0.76 for affective dimensions) (Wright, Asmundson, & McCreary, 2001), and reportedly has face and content validity, and test-retest reliability (Grimmer-Somers et al., 2009).

3.4.6.3 Position awareness tests

Spinal reposition sense and sagittal range of movement were assessed by a flexible M180B electrogoniometer (Figure 2:1) (Biometrics Ltd, Gwent, UK) connected by leads to a DataLINK system (Figure 2:2) with management version 2.0 software. For details on the electrogoniometer see Chapter 2.

Calibration of electrogoniometer immediately prior to testing position sense

Immediately prior to testing each participant, the electrogoniometer was calibrated to 0 degrees and moved through a known angle of 90 degrees and back to 0 degrees to ensure accuracy within a degree.

Protocol for estimating acuity of low back position sense

To enable observation during testing, participants wore shorts and a t-shirt. Low back position awareness was assessed by an electrogoniometer placed over the lumbosacral spine using double-sided sticky tape (Hurley et al., 2000). The electrogoniometer was turned on at least 10-minutes before use to allow its temperature to stabilise as a consequence of heating due to electrical current (Jonsson et al., 2001). The upper part of the lower arm of the electrogoniometer was then placed on the lower aspect of the S1 spinous process and the lower part of the upper arm of the electrogoniometer was placed on the upper aspect of the L1 spinous process. The researcher was the only person attaching the electrogoniometer to negate issues with inter-therapist reliability (Gonnella, Paris, & Kutner, 1982; Matyas & Bach, 1985; Panzer, 1992; Seffinger et al., 2004). The spinous processes were located, based on knowledge of their shapes and sizes, a method shown in previous research undertaken by the researcher, to improve

accuracy of manual examination of the low back (Phillips, Barnard, Mullee, & Hurley, 2009). In addition, the researcher confirmed movement at L5/S1 by palpating intervertebral movement during active movement in the sagittal plane either during sitting or standing, and counted up from the sacrum to locate the L1 spinous process.

It is acknowledged that the reliability of the researcher in locating spinous processes was not tested and no "gold standard" was used to ensure the accuracy of identifying the sacrum and L1 in this research. Therefore uncertainty exists as to the validity of this assessment, however the researcher has clinical and research experience in these approaches, and has previously published work investigating the accuracy in locating of lumbar spinous processes (Phillips et al., 2009). In addition, the researcher took all measurements on all participants to ensure consistency of the testing procedures.

It is however, acknowledged that in a patient population accuracy of locating spinal segments would be affected by sacralisation or lumbarisation (4 lumbar vertebrae and 6 lumbar vertebrae, respectively). The lowest lumbar segment that moved was therefore considered as L5. Only by the use of X-ray analysis would it be possible to absolutely confirm the segmental location of L1 and S1. This however, would not be possible due to logistical or ethical reasons related to exposure to radiation for participants.

The participants were advised that test movements should not reproduce any LBP and if this occurred, they were to stop, return to the upright position and report it to the investigator. All participants were given verbal instructions and shown the test procedures, before performing each position sense test.

In standing

Each participant, standing with their feet shoulder width apart, initially adopted an upright standing posture, with a neutral lumbosacral spine. Using the researchers' spine as an example, it was explained to participants this posture was to be a comfortable lumbar lordotic

position, avoiding outer ranges of movement. This position was then calibrated to 0 degrees for the electrogoniometer. Each participant was asked to bend forward (flex) and backward (extend), as far as possible. The total range of comfortable, pain-free spinal movement in the sagittal plane, was recorded.

The participant was then blindfolded with their arms folded in front of and away from the body, so that feedback on spinal position awareness from contact of the arms with the body was avoided. They were asked to bend their low back slowly forward (Figure 3:1) or backward (Figure 3:2) and were stopped by the investigator at a random "target" position avoiding end of range (with reference to their range of spinal movement noted above). They held this "target" position for 3-seconds (Maffey-Ward et al., 1996), before returning to the neutral spinal posture. The participant then attempted to return to the "target" position; the position they returned to was termed the "reproduced" position. Finally, they again returned to the neutral spinal posture. This procedure was repeated for 10 random "target" positions. At the end of each random target position test, participants could rest their arms to prevent their muscles aching in the upper back and upper limbs to avoid this distracting them from the test procedure.

Ten tests were chosen, as 6 or more position awareness tests are recommended to ensure stability of a participant's proprioceptive function (Allison & Fukushima, 2003). Ten tests have also been recommended in other studies testing position sense (Hurley & Ng, 1996; Hurley et al., 1998a).

For all participants, 8 of the 10 standing tests were into flexion because this movement has greater range and 2 were into extension. The sequence of the 8 tests into flexion (3 into slight flexion; 3 into mid flexion; 2 into outer flexion) and 2 tests into extension was standardised for all, so that only the specific angle of each random "target" positions were different, as this was not possible to standardise with the equipment and testing procedure used.

Figure 3:1. Attachment of electrogoniometer and low back flexion position in standing

Figure 3:2. Low back extension position in standing

In sitting

Each participant sat on the side of a treatment couch, with their hips and knees at approximately 90 degrees flexion, and their feet on the ground, shoulder-width apart. Each participant adopted a comfortable, upright “neutral” low back posture. The position was confirmed by the researcher as alignment in the horizontal plane of the inferomedial aspect of the anterior superior iliac spine and the posterior superior iliac spine (Maffey-Ward et al., 1996) and feedback was given if it was felt necessary in order to achieve this posture. This “neutral” low back posture was calibrated to 0 degrees for the electrogoniometer. The total range of comfortable pain-free spinal movement in the sagittal plane was recorded, from full slump sitting into extension, including pelvic tilting.

Participants were then blindfolded with their arms folded in front of and away from their body. They were asked to slump (Figure 3:3) or extend (Figure 3:4) their low back slowly and were stopped by the investigator at a random “target” position avoiding end of range (with reference to their range of spinal movement noted above). They held this “target” position for 3-seconds (Maffey-Ward et al., 1996), before returning to the neutral spinal posture. The participant then attempted to return to the “target” position; the position they returned to was termed the “reproduced” position. Finally, they again returned to the neutral spinal posture. This procedure was repeated for 10 random “target” positions. Again, at the end of each random target position test, participants could rest their arms to prevent muscles aching in the upper back and upper limbs, and distracting them from the test procedure.

For all participants, 8 of the 10 sitting tests were into flexion and 2 were into extension, with the sequence repeated as for standing.

Figure 3:3. Attachment of electrogoniometer and low back flexion position in sitting

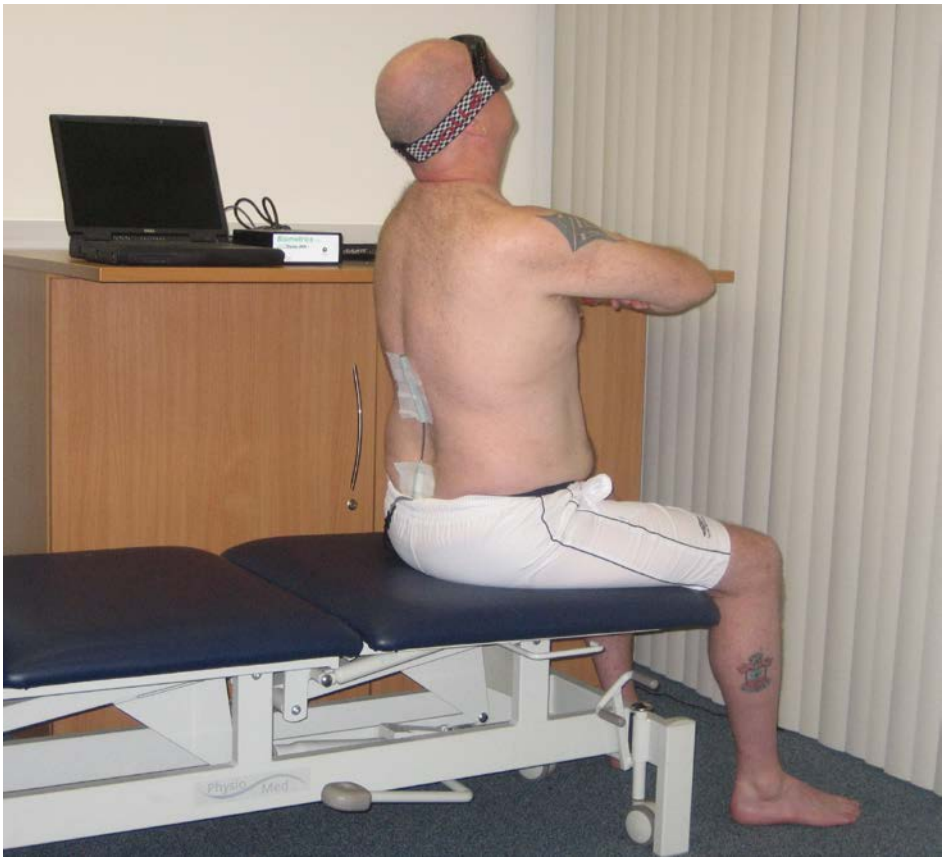


Figure 3:4. Low back extension position in sitting

The order in which the sitting and standing position awareness tests were carried out was randomised using a simple randomisation process (Friedman, Furberg, & DeMets, 1998). By varying the start position between participants, it enabled investigation of any possible learning effect i.e. was it more likely that the second test start position, resulted in better position awareness results, due to a learning effect from the testing in the initial start position. Data collection for all the position awareness tests of the low back (standing and sitting), took a maximum of 20 minutes in total for each participant.

Following testing, the blindfold and the electrogoniometer were removed from the participant and the skin washed to remove any residue of the double-sided sticky tape. The skin was inspected, but no reactions to the tape were observed.

Test-retest of position awareness tests

For each of the position awareness tests, test-retest data were recorded for ten people with and ten people without LBP. Data were collected under the same conditions on a different day to allow comparison.

Reposition error in the elbow

To eliminate the possibility that proprioceptive deficits were due to a global problem of sensory deficits or central processing, rather than a local disturbance to the sensory function of the spine, the proprioceptive acuity of a peripheral joint - the elbow - was also assessed in all participants. The elbow was chosen because it is an easy joint to view and measure. Also, alterations in sensorimotor function in the low back are unlikely to affect upper limb sensorimotor function, but could have potentially affected this in the lower limb, for example if measuring the knee joint instead.

Each participant's elbow position awareness was assessed with the centre of the electrogoniometer placed over the humeroradial joint line

on the lateral side of the elbow using double-sided sticky tape and connected to the dataLINK system. The dominant elbow was tested to allow consistency of testing across participants, but if there was a history of pain or injury in this elbow the non-dominant side was tested. Participants were advised that movements should not reproduce any pain and if this occurred, they were to stop, return to start position and report it to the investigator.

Full extension at the elbow was recorded as the “start” position and calibrated to 0 degrees for the electrogoniometer. The participant was asked to bend (flex) their elbow to establish their comfortable total range of movement. The participant was then asked to return to the “start” position. They were then blindfolded and asked to bend (flex) their elbow slowly, with no contact allowed between the upper arm and body to prevent any feedback on position sense. They were stopped by the researcher at a random “target” position avoiding end-range. They held this “target” position for 3-seconds before returning to the “start” position. The participant then attempted to return to the “target” position; the position they returned to was termed the “reproduced” position. This procedure was repeated for 10 random “target” positions.

The blindfold and electrogoniometer were removed and the skin washed to remove any residue of the double-sided sticky tape.

3.4.7 Data analysis

3.4.7.1 Participant data

Means, standard deviation and ranges are reported for participant characteristics: age; weight, height and body mass index (BMI). In addition, for participants with LBP the means, standard deviation and ranges are reported for self reported disability; pain scores; the length in time of the history of recurrent LBP (years) and the average duration of recurrent episodes of LBP (days).

3.4.7.2 Data processing

Data collected by the electrogoniometer were recorded using the DataLog system. The data were then exported anonymously in ASCII format to a University workstation. Geodata, a computer consultancy company at the University of Southampton, converted all participants ASCII data into degrees. The relevant “target” and “reproduced” positions in degrees, were then transferred automatically into a SPSS database by Geodata. An independent person coded LBP and NLBP groups, so that the researcher remained “blinded” to participants back pain status during data analysis. All data analyses were performed using SPSS version 12.0, SPSS version 14.0 and SPSS version 18.0 statistical software (SPSS, Chicago, Illinois, USA). For Bland and Altman tests of agreement for the test-retest data, the data were transferred from SPSS into an Excel spreadsheet. Both SPSS and Excel were chosen for this study and used throughout the thesis, because of their appropriateness and availability through the University and because the researcher had experience in their use.

3.4.7.3 Assessment of joint position sense acuity

The statistical analysis presented is a stand-alone comparison of low back position sense in participants with and without LBP, both before-work and after-work. It is not a within-group comparison of position sense before and after-work in each participant group.

The data point used for analysis for each “target” position was recorded at the end of the 3-second hold, equating to the timing when participants were asked to “remember this position.” Data for the analysis of each “reproduced” position were recorded when the participant indicated they had found the “target” position. Data for the analysis of each upright “neutral” low back posture were recorded when the participant had initially reproduced the neutral spinal posture.

For the standing, sitting and elbow tests, the absolute error between the “target” and “reproduced” position, was calculated in degrees, for each of the 10 reposition tests. In addition, the absolute error between the initial “neutral” low back posture in standing and sitting, and each “reproduced” “neutral” low back posture, was calculated in degrees. The reposition error for each participant, for each test, was then calculated as a mean of these 10 absolute error values. This was taken to be the joint position sense for each participant, with a greater reposition error value indicating poor position sense, i.e. poorer position acuity. Data that were not normally distributed were natural log-transformed before analysis (Altman, 1991), as skewed distributions can become symmetrical, allowing the use of parametric analysis (Bland & Altman, 1996). The average mean reposition error or each test, was then calculated for the LBP and NLBP group and compared using a two sample t-test, with level of significance $P < 0.05$. To minimise the possibility of finding a significant result by chance, the level of significance for secondary hypothesis was set at $P < 0.01$ (i.e. a 1% possibility of a chance finding when $P < 0.01$, versus a 5% possibility of a chance finding when $P < 0.05$).

The two sample t-test was chosen for comparing the error in position sense data (measured in degrees) between two groups (participants with and without LBP), and allows for calculation of 95% confidence intervals. It is a “robust” statistical test and appropriate even when the measurement data deviates moderately from the normal distribution (Everitt, 2006). Although the t-test is “robust”, a normal distribution (on the original data scale or on the natural log-transformed scale) was

required, to allow parametric analysis (Hicks, 1995). Geometric means are presented to allow comparisons between groups on the original data scale i.e. in degrees (Altman, 1991).

Any correlation between position sense acuity and pain; disability; years since onset of LBP in the past year and the average duration of recurrent episodes of LBP, was evaluated using Pearson's product movement correlation coefficient (*r*) (Hicks, 1995). Again, to minimise the possibility of finding a significant result by chance, the level of significance was set at $P < 0.01$.

3.4.7.4 Test-retest of the position awareness tests

For test-retest of joint position sense acuity, the data are presented as mean error values for ease of comparison. The reposition error for each participant, for each test, was calculated as a mean of the 10 absolute error values (see 3.4.7.3). The results for testing on day 1 and day 2 were compared. The greater the difference in error values between test 1 and test 2, the poorer the test-retest reliability when interpreted using the raw data.

Bland and Altman tests of agreement between measurements that includes the mean difference (SD), 2xSD and 95% limits of agreement, and ICC's and the 95% CI for the ICCs are also presented (Bland et al., 1986; Rankin et al., 1998).

For ICCs, the formulae (3,1) was chosen because of the single rater used in this study and future studies in this thesis. Of the other formulae ICC (1,1) has minimal clinical use and can lead to an underestimation of the true correlation, (2,1) is more appropriate when there are multiple raters and (1,*k*), (2,*k*) and (3,*k*) are used when a mean correlation value is calculated either from more than one test or from more than one rater (Müller et al., 1994; Shrout et al., 1979):

$$\text{ICC (3,1)} = \frac{\text{subject variability}}{\text{subject variability + random error variability}}$$

3.5 Results

3.5.1 Participant characteristics

It was planned to recruit 120 particpants, although only 101 were recruited in total. Of these 101 participants, 61 had LBP and 40 had NLBP. They were recruited from sedentary (26 LBP and 30 NLBP), manual (22 LBP and 7 NLBP) and driving (13 LBP and 3 NLBP) occupations. The difficulties in recruiting participants and the subsequent discrepancy in participant numbers in occupational groups are discussed in section 3.6.

More females were recruited in both groups. The height recorded was similar in participants with and without LBP, but the mean body weight was greater in participants with LBP (Table 3:1).

Participant characterisitics for the occupational groups are shown in Appendix 3:10abc. Drivers without LBP were younger than drivers with LBP, but this is possibly a reflection on the disparity between participant numbers. Other participant characteristics were similar for different occupational groups.

Table 3:1. Participant characteristics

		LBP *n=61*	**NLBP *n=40***
Age in years	Mean (SD) Median (range)	44.1 (9.8) 45 (19, 60)	41.8 (9.1) 40.5 (22, 60)
Male / female		27/34	13/27
Weight in kg	Mean (SD) Median (range)	74.9 (14.2) 73 (49, 111)	67.4 (13.2) 65.5 (50, 106)
Height in cm	Mean (SD) Median (range)	171.5 (9.8) 170 (152, 198)	170.8 (9.6) 170 (155, 197)
Body mass index (BMI)	Mean (SD) Median (range)	24.8 (3.6) 24.5 (17, 34.6)	23.9 (3.8) 23.8 (15.5, 33.5)
Years since onset of LBP	Mean (SD) Median (range)	11.8 (10.8) 7 (0.58, 40)	
Duration of LBP episodes in days	Mean (SD) Median (range)	11.4 (24) 2.3 (1, 105)	

Footnote: For years since onset of LBP, 3 participants were unable to specify (n=58)**.** For average duration of LBP episodes, 15 participants were unable to specify (n=46)

Before and after-work self-reported disability (RDQ) and SF-MPQ scores for all participants with LBP are presented in Table 3:2. Drivers had consistently higher values, possibly due to disparity between participant numbers (see Appendix 3:11abc).

Table 3:2. Self-reported disability (RDQ) and pain scores (SF-MPQ) (n = 61)

		Before-work	After-work
RDQ	Mean (SD) Median (range)	4.4 (4.8) 2 (0, 17)	4.7 (4.9) 3 (0, 19)
SF-MPQ:			
pain rating index rank values	Mean (SD) Median (range)	1.9 (2.5) 1 (0, 11)	3.2 (4.2) 1 (0, 19)
visual analogue score (VAS) for level of pain 0-100mm	Mean (SD) Median (range)	11.5 (13.5) 8 (0, 65)	18.2 (20.8) 11 (0, 73)
present pain index	Mean (SD) Median (range)	0.9 (0.8) 1 (0, 3)	1.1 (0.8) 1 (0, 3)

Footnote: RDQ and SF-MPQ questions relate to the day of testing. RDQ scores are out of 23; see section 3.5.6.2 for information on scoring the SF-MPQ.

The median duration between before- and after-work tests (inter-quartile range) in LBP was 7.0 days (4 to 16) and in NLBP was 4.5 days (2.3 to 8.0). The difference in days between people with and without LBP was due to their availability for testing. Ideally this duration would be equivalent; however the researcher had to work around the availability of the participants and owing to the difficulties recruiting, was not in a position to exclude participants if they were not available on a particular day. It is recognised that this difference could have made a difference in the test results, but there was no obvious effect when observing the data. Unfortunately there is uncertainty as to the participant's level of pain and disability between tests, as the participant's RDQ and SF-MPQ scores are only known for the day of testing.

3.5.1.1 Participant characteristics for test-retest data

The participant characteristics for test-retest data for participants with and without LBP were similar, except weight and height which were higher in people with LBP (Table 3:3).

Table 3:3. Participant characteristics for test-retest data

		LBP *n=10*	NLBP *n=10*
Age in years	Mean (SD) Median (range)	47.9 (6.7) 49.5 (38, 57)	45.8 (9.5) 46.5 (31, 60)
Male / female		2/8	3/7
Weight in kg	Mean (SD) Median (range)	79 (21.7) 70 (51, 111)	60.9 (8.8) 60 (50, 72)
Height in cm	Mean (SD) Median (range)	172.3 (9.7) 169.5 (161, 189)	165.8 (9) 164 (155, 184)
Body mass index (BMI)	Mean (SD) Median (range)	23.8 (3.3) 23 (19.7, 30.1)	23.5 (3.1) 24 (19.5, 28.3)
Years since onset of LBP	Mean (SD) Median (range)	13.3 (12.2) 9.5 (1, 31)	
Duration of LBP episodes in days	Mean (SD) Median (range)	27.1 (35.8) 21 (1.5, 105)	

The mean score for self-reported disability (RDQ) for the ten participants with LBP and for SF-MPQ were similar for Day 1 and Day 2 (Table 3.4).

Table 3:4. Self-reported disability (RDQ) and pain scores (SF-MPQ) for test-retest data (n = 10)

		Day 1	Day 2
RDQ	Mean (SD) Median (range)	2.8 (2.9) 2 (0, 8)	1.7 (2.2) 1.5 (0, 7)
SF-MPQ:			
pain rating index rank values	Mean (SD) Median (range)	0.8 (0.9) 1 (0, 3)	1 (0.8) 1 (0, 3)
visual analogue score (VAS) for level of pain 0-100mm	Mean (SD) Median (range)	7.7 (10.6) 3.5 (0, 33)	5.6 (6.2) 4.5 (0, 18)
present pain index	Mean (SD) Median (range)	0.8 (1) 0.5 (0, 3)	0.8 (0.6) 1 (0, 2)

Footnote: RDQ and SF-MPQ questions relate to the day of testing. RDQ scores are out of 23; see section 3.5.6.2 for information on scoring the SF-MPQ.

3.5.2 Position awareness of the low back in all participants before and after-work

When attempting to reproduce the 10 "target" angles, the before-work data were only found to be normally distributed for the standing tests (Appendix 3:12), and the after-work data were only found to be normally distributed for the sitting tests. The remaining data were natural log-transformed and the previously skewed data were found to be normally distributed, allowing for parametric analysis (Appendix 3:13).

Both before and after a shift of work, there were no differences in low back position acuity between participants with and without LBP, when attempting to reproduce the 10 "target" positions (Table 3:5), or when returning to the neutral spinal posture (Table 3:6). Errors were greatest when returning to the neutral spinal posture in sitting. Before-work, participants with LBP had slightly higher average error values when attempting to return to the neutral low back sitting posture, suggesting a trend towards them finding it more difficult to discriminate this position than participants with NLBP.

Table 3:5. Error in low back position awareness in all participants*

	LBP *n=61*	NLBP *n=40*	mean difference [95% CI]	P value
Before-work				
Standing	2.48 (1.04)	2.21 (0.65)	-0.27 [-0.60 to 0.07]	0.118
Sitting	1.60[a]	1.63[a]		
	0.47 (0.49)	*0.49 (0.45)*	*0.02 [-0.17 to 0.21]*	0.824
After-work				
Standing	2.32[a]	2.19[a]		
	0.84 (0.43)	*0.78 (0.49)*	*-0.06 [-0.24 to 0.13]*	0.536
Sitting	1.85 (0.76)	1.83 (0.69)	-0.02 [-0.31 to 0.28]	0.942

*Data are mean degrees (SD)
[a] = geometric mean allows comparison on original degrees data scale (Altman, 1991)
italic = natural log-transformed value
95% CI = 95 percent confidence interval

Table 3:6. Error in low back position awareness returning to the neutral low back posture in all participants*

	LBP *n=61*	NLBP *n=40*	mean difference [95% CI]	P value
Before-work				
Standing	1.97[a]	2.36[a]		
	0.68 (0.57)	*0.86 (0.63)*	*0.18 [-0.06 to 0.42]*	0.149
Sitting	4.83[a]	4.01[a]		
	1.58 (0.65)	*1.39 (0.56)*	*-0.19 [-0.44 to 0.06]*	0.137
After-work				
Standing	2.00[a]	2.15[a]		
	0.70 (0.65)	*0.76 (0.57)*	*0.07 [-0.18 to 0.32]*	0.581
Sitting	4.38[a]	4.36[a]		
	1.48 (0.67)	*1.47 (0.54)*	*-0.004[-0.26 to 0.25]*	0.973

*Data are mean degrees (SD)
[a] = geometric mean allows comparison on original degrees data scale (Altman, 1991)
italic = natural log-transformed value
95% CI = 95 percent confidence interval

The order of testing position awareness between sitting and standing was randomised as discussed in section 3.4.6.3, to minimise the effect of learning, but this did not alter the findings either before or after-work, suggesting no learning effect occurred.

On secondary analysis of the before and after-work data, comparing only the 8 forward bending (flexion) reposition tests, the error values were found to be similar with no differences in reposition error between participants with and without LBP. A similar finding occurred when comparing only the 2 backward bending (extension) reposition tests.

In order to look at the stability of the error values in the different groups, and in particular to see if reposition error progressively worsened as the trunk muscles were required to perform the repetitive reposition tasks, there was comparison of the first 5 reposition tests between participants with and without LBP, and the second 5 reposition tests. In this analysis, the error values were also found to be similar to the primary analysis and no differences were found when comparing the reposition error between LBP and NLBP groups, either before or after-work.

3.5.3 Position awareness of the low back in occupational groups before and after-work

When attempting to reproduce the 10 “target” angles, the before-work data were found to be normally distributed for the standing tests, and the after-work data were found to be normally distributed for the sitting tests. The data for the remaining tests were not normally distributed and therefore were natural log-transformed. These previously skewed data were found to be normally distributed allowing for parametric analysis.

Analysis by occupation, showed similar findings to the primary analysis, with no significant differences in position awareness between participants with and without LBP when attempting to reproduce the 10 “target” positions before or after a shift of work (Tables 3:7 and 3:8).

Table 3:7. Error in low back position awareness in sedentary (n=26 LBP /30 NLBP), manual (n=22/7) and driving (n=13/3) occupations before-work*

	LBP	NLBP	mean difference [95% CI]	P value
Standing:				
Sedentary	2.68 (1.09)	2.23 (0.70)	-0.45 [-0.94 to 0.03]	0.068
Manual	2.63 (1.04)	2.27 (0.47)	-0.36 [-1.20 to 0.49]	0.392
Driving	1.81 (0.65)	1.85 (0.63)	0.04 [-0.85 to 0.92]	0.925
Sitting:				
Sedentary	1.36[a]	1.60[a]		
	0.31 (0.51)	*0.47 (0.46)*	*0.17 [-0.09 to 0.43]*	0.205
Manual	1.99[a]	1.75[a]		
	0.69 (0.35)	*0.56 (0.38)*	*-0.13 [-0.45 to 0.19]*	0.414
Driving	1.51[a]	1.60[a]		
	0.41 (0.54)	*0.47 (0.58)*	*0.06 [-0.69 to 0.80]*	0.872

Table 3:8. Error in low back position awareness in sedentary (n=26 LBP /30 NLBP), manual (n=22/7) and driving (n=13/3) occupations after-work*

	LBP	NLBP	mean difference [95% CI]	P value
Standing:				
Sedentary	2.66[a]	2.18[a]		
	0.98 (0.39)	*0.78 (0.51)*	*-0.20 [-0.45 to 0.04]*	0.103
Manual	2.20[a]	2.08[a]		
	0.79 (0.46)	*0.73 (0.53)*	*-0.06 [-0.48 to 0.37]*	0.775
Driving	1.90[a]	2.61[a]		
	0.64 (0.39)	*0.96 (0.32)*	*0.32 [-0.21 to 0.84]*	0.215
Sitting:				
Sedentary	1.60 (0.78)	1.81 (0.71)	0.21 [-0.19 to 0.61]	0.296
Manual	2.18 (0.67)	2.00 (0.74)	0.18 [-0.79 to 0.43]	0.555
Driving	1.78 (0.70)	1.72 (0.27)	-0.06 [-0.96 to 0.84]	0.886

*Data are mean degrees (SD)
(n =*LBP/NLBP)*
[a] = geometric mean
italic = natural log-transformed value
95% CI = 95 percent confidence interval

Errors were generally greater when returning to the neutral sitting posture (Tables 3:9 and 3:10). Before-work, in drivers, the greatest differences in position awareness were found between participants with and without LBP, when returning to the neutral standing posture (Table 3:9). After-work, both in the driver and manual worker groups, participants with LBP found it harder to return to the neutral sitting posture (Table 3:10). These findings should only be considered as trends due to the large disparity in participant numbers however, and the inability to recruit the number of participants (20 LBP and 20 NLBP participants) in the occupational groups for manual workers and drivers, based on the sample size calculation (see section 3.4.4).

Table 3:9. Error in low back position awareness in sedentary (n=26 LBP /30 NLBP), manual (n=22/7) and driving (n=13/3) occupations when returning to the neutral low back posture before-work*

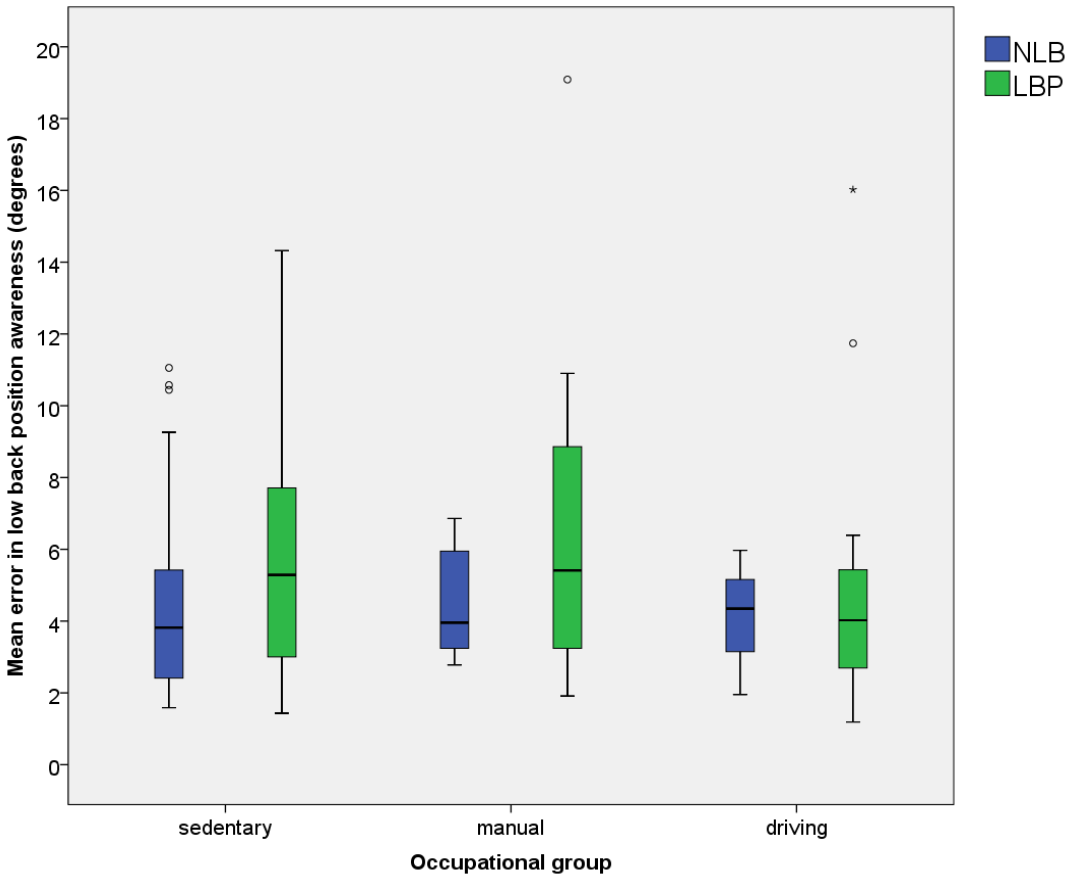
	LBP	NLBP	mean difference [95% CI]	P value
Standing:				
Sedentary	1.99[a]	2.27[a]		
	0.69 (0.59)	*0.82 (0.64)*	*0.13 [-0.20 to 0.46]*	0.444
Manual	1.97[a]	2.29[a]		
	0.68 (0.66)	*0.83 (0.56)*	*0.15 [-0.42 to 0.71]*	0.602
Driving	1.93[a]	3.74[a]		
	0.66 (0.37)	*1.32 (0.74)*	*0.66 [0.06 to 1.27]*	0.034
Sitting:				
Sedentary	4.66[a]	3.97[a]		
	1.54 (0.67)	*1.38 (0.60)*	*-0.16 [-0.50 to 0.18]*	0.353
Manual	5.64[a]	4.31[a]		
	1.73 (0.58)	*1.46 (0.37)*	*-0.27 [-0.74 to 0.21]*	0.261
Driving	4.01[a]	3.71[a]		
	1.39 (0.71)	*1.31 (0.58)*	*-0.08 [-1.03 to 0.87]*	0.856

Table 3:10. Error in low back position awareness in sedentary (n=26 LBP /30 NLBP), manual (n=22/7) and driving (n=13/3) occupations when returning to the neutral low back posture after-work*

	LBP	NLBP	mean difference [95% CI]	P value
Standing:				
Sedentary	1.75[a]	2.10[a]		
	0.56 (0.62)	*0.74 (0.53)*	*0.17 [-0.13 to 0.48]*	0.259
Manual	2.69[a]	2.64[a]		
	0.99 (0.72)	*0.97 (0.67)*	*-0.01 [-0.64 to 0.62]*	0.971
Driving	1.58[a]	1.70[a]		
	0.46 (0.41)	*0.53 (0.87)*	*0.07 [-1.96 to 2.09]*	0.905
Sitting:				
Sedentary	4.53[a]	4.81[a]		
	1.51 (0.82)	*1.57 (0.52)*	*-0.06 [-0.31 to 0.44]*	0.742
Manual	4.90[a]	3.94[a]		
	1.59 (0.45)	*1.37 (0.55)*	*-0.22 [-0.64 to 0.20]*	0.292
Driving	3.39[a]	2.12[a]		
	1.22 (0.64)	*0.75 (0.13)*	*-0.47 [-0.88 to -0.06]*	0.028

*Data are mean degrees (SD)
(n =*LBP/NLBP)*
[a] = geometric mean
italic = natural log-transformed value
95% CI = 95 percent confidence interval

In both the before-work and after-work data, the greatest spread of error values, when returning to neutral sitting posture, were found in sedentary workers with LBP. This could just be a reflection of the higher number of participants in the sedentary group. This however, would not account for the greater spread in error values between people with and without LBP in the sedentary group, as more people without LBP were recruited (Figures 3:5 and 3.6).

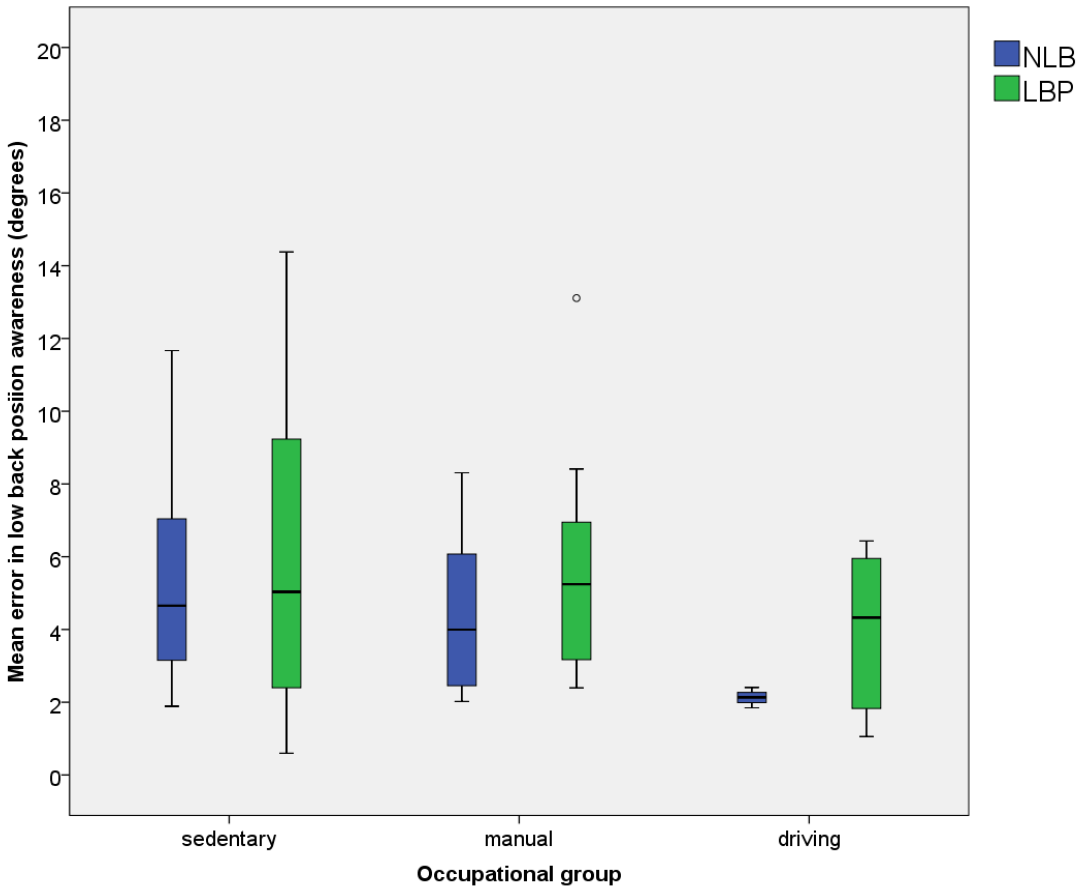


Footnote: The ends of the whiskers represent the maximum and minimum values, excluding outliers (see o below) and extreme values (see * below). The bottom of the box is the 25th percentile, the horizontal line in the box represents the median value (50th percentile) and the top of the box is the 75th percentile

o = outlier value more than $1^1/_2$ times the inter-quartile range away from the top of the box

* = extreme value more than 3 times the inter-quartile range away from the top of the box

Figure 3:5. Box and whisker plot of position awareness returning to the neutral low back posture in sitting before-work



Footnote: The ends of the whiskers represent the maximum and minimum values, excluding outliers (see o below) and extreme values (see * below). The bottom of the box is the 25th percentile, the horizontal line in the box represents the median value (50th percentile) and the top of the box is the 75th percentile

o = outlier value more than $1^1/_2$ times the inter-quartile range away from the top of the box

* = extreme value more than 3 times the inter-quartile range away from the top of the box

Figure 3:6. Box and whisker plot of position awareness returning to the neutral low back posture in sitting after-work

On secondary analysis of the before and after-work data, comparing only the 8 forward bending (flexion) reposition tests, the error values were found to be similar with no differences in reposition error between participants with and without LBP in the different occupational groups. A similar finding occurred when comparing only the 2 backward bending (extension) reposition tests.

Also before and after-work, there were no differences in the error values when comparing the first 5 reposition tests between participants with and without LBP in the different occupational groups, and the second 5 reposition tests.

3.5.4 BMI. Its relationship to reposition error

No correlation was found between BMI and position sense in all participants with LBP (Pearson correlation r value range from -0.15 to 0.13), or participants without LBP (Pearson correlation r value range from -0.18 to 0.18).

3.5.5 Pain and disability scores. Their relationship to reposition error

No correlation was found between position sense and pain, and position sense and disability in all participants with LBP, either before-work (Pearson correlation r value range from -0.24 to 0.20), or after work (Pearson correlation r value range from -0.32 to 0.09).

3.5.6 Years since onset of LBP and the average duration of recurrent episodes. Their relationship to reposition error

No correlation was found between position sense and the number of years since onset of LBP (Pearson correlation r value range from -0.29 to 0.09), and position sense and the average duration of recurrent episodes in all participants with LBP (Pearson correlation r value range from -0.27 to 0.12).

3.5.7 Position sense at the elbow

Two participants with LBP had history of elbow pain in their dominant arm and their non-dominant arm was therefore tested.

Data were found to be normally distributed, allowing for parametric analysis, and no differences in elbow joint position sense were found between participants with and without LBP (Table 3:11).

Table 3:11. Error in elbow position awareness in all participants*

	LBP *n=61*	NLBP *n=40*	mean difference [95% CI]	P value
Error in elbow	5.40 (2.23)	5.14 (2.82)	-0.26 [-1.27 to 0.73]	0.594

*Data are mean degrees (SD)

3.5.8 Test-retest of position awareness tests

The difference in mean error scores in degrees between day 1 and day 2, for people with and without LBP, were small for all position awareness tests (Tables 3:12 to 3:15). Mean differences for Bland and Altman were also small for people with and without LBP, between day 1 and day 2. The values for the 95% limits of agreement were smaller for the position awareness test-retest data in standing (Table 3:12) and sitting (Table 3:13), larger for the return to neutral in standing (Table

3:14) and much larger for the return to neutral in sitting (Table 3:15). ICC coefficient values ranged from -0.01 to 0.73 and were consistently better in the people with LBP. Of note however, the mean differences between day 1 and day 2 in all the tests, and the 95% limits of agreement for all but one of the tests, were smaller for people without LBP. The 95% CIs for ICCs were wide for all test-retest position awareness tests, suggesting uncertainty as to the true reliability of each of the tests (as measured by ICCs) (Tables 3:12 to 3:15).

Table 3:12. Position awareness test-retest - standing. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP Reposition error		NLBP Reposition error	
Participant	**Day 1**	**Day2**	**Day 1**	**Day 2**
1	2.22	2.77	2.22	2.90
2	3.42	3.42	2.19	1.17
3	1.83	1.17	2.17	2.60
4	1.71	4.45	3.33	2.39
5	1.01	1.44	2.58	3.01
6	1.63	2.68	1.68	3.89
7	2.25	2.90	2.91	1.61
8	2.96	2.90	3.10	2.82
9	2.17	2.14	1.50	1.45
10	4.25	2.34	2.27	1.99
Bland & Altman				
Mean difference (SD)	0.28 (1.19)		-0.01 (1.03)	
2xSD	2.39		2.05	
95% limits of agreement	-2.11 to 2.67		-2.07 to 2.04	
ICC coefficient	0.21		-0.01	
95% CI	-0.45 to 0.72		-0.61 to 0.60	

Table 3:13. Position awareness test-retest in sitting. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP Reposition error		NLBP Reposition error	
Participant	**Day 1**	**Day2**	**Day 1**	**Day 2**
1	1.26	1.57	1.97	1.94
2	1.13	1.12	1.53	2.02
3	0.92	1.69	0.90	1.59
4	0.59	1.18	2.65	1.51
5	0.68	1.12	1.59	1.28
6	2.11	1.23	2.41	3.73
7	0.65	1.60	2.70	1.47
8	2.28	2.33	2.62	2.43
9	1.79	1.05	2.54	1.63
10	1.99	1.88	2.71	3.40
Bland & Altman				
Mean difference (SD)	0.14 (0.60)		-0.06 (0.86)	
2xSD	1.21		1.72	
95% limits of agreement	-1.07 to 1.34		-1.78 to 1.66	
ICC coefficient	0.39		0.33	
95% CI	-0.28 to 0.80		-0.34 to 0.79	

Table 3:14. Test-retest returning to neutral standing. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP Reposition error		NLBP Reposition error	
Participant	**Day 1**	**Day2**	**Day 1**	**Day 2**
1	1.02	1.50	4.05	2.97
2	2.13	2.05	0.57	0.86
3	3.65	0.51	1.01	1.23
4	2.04	2.95	2.59	2.54
5	1.90	1.13	1.00	3.87
6	6.45	5.40	2.26	2.28
7	1.65	1.41	2.94	1.78
8	0.87	1.64	2.51	1.58
9	1.71	2.59	1.08	1.24
10	3.88	1.67	5.36	3.99
Bland & Altman				
Mean difference (SD)	-0.45 (1.37)		-0.10 (1.23)	
2xSD	2.74		2.45	
95% limits of agreement	-3.19 to 2.30		-2.56 to 2.35	
ICC coefficient	0.60		0.57	
95% CI	0.01 to 0.88		-0.05 to 0.87	

Table 3:15. Test-retest returning to neutral sitting. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP Reposition error		NLBP Reposition error	
Participant	**Day 1**	**Day2**	**Day 1**	**Day 2**
1	8.30	14.38	2.72	7.76
2	3.00	3.53	3.82	2.33
3	10.33	7.07	3.62	4.52
4	5.18	2.11	3.81	5.90
5	6.71	1.71	9.26	4.98
6	3.28	5.81	2.28	3.15
7	1.73	4.34	4.63	4.52
8	14.32	13.63	4.34	5.42
9	1.49	0.60	9.11	7.97
10	4.32	3.75	7.14	3.09
Bland & Altman				
Mean difference (SD)	-0.17 (3.28)		-0.11 (2.80)	
2xSD	6.56		5.60	
95% limits of agreement	-6.73 to 6.39		-5.71 to 5.49	
ICC coefficient	0.73		0.21	
95% CI	0.23 to 0.93		-0.45 to 0.72	

3.6 Discussion

3.6.1 Position awareness in the low back before and after work

For the primary hypothesis / analysis, this study found no differences in the accuracy of low back position awareness, before or after a shift of work, between participants with and without LBP. The greatest reposition errors were recorded when participants attempted to return to the neutral spinal posture. There was a trend however; suggesting largest reposition errors were evident in LBP participants when returning to the neutral sitting posture, but only before-work.

In addition for the secondary hypothesis / analysis, sedentary occupation did not have any effect on low back position acuity. Unfortunately, uncertainty exists about the effect of occupation on position sense in manual and driving workers, as the sample sizes in these occupations were too small. After-work, participants with LBP who were drivers or manual workers did find it harder to return to the neutral sitting posture however, but this was most likely due to the disparity in LBP and NLBP participant numbers, within these occupational groups.

The similarities of spinal position awareness between participants with and without LBP are broadly supported in some studies (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000), but not others that found a position awareness deficit in participants with LBP (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003).

Possible reasons for a discrepancy between studies, includes differences in the severity of LBP, small sample sizes (Descarreaux et al., 2005; O'Sullivan et al., 2003), heterogeneous populations, poor “control groups” - the participants with NLBP may have had previous LBP (Gill et al., 1998; Newcomer et al., 2000), a specific sub group population of LBP sufferers with lumbar instability (O'Sullivan et al.,

2003), methodological variations in assessment procedures (Preuss, Grenier, & McGill, 2003), and performing less than the recommended 6 or more position awareness tests (Allison et al., 2003). In this study a relatively large number of participants were recruited for the primary analysis and for the sub-group analysis in sedentary workers, with strict inclusion/exclusion criteria, particularly for participants with NLBP, and averaged the error of 10 test positions for low back flexion and extension movements.

The small position awareness errors evident in this study, during random "target" positions in lumbar flexion and extension, are similar to other studies (Brumagne et al., 2000; Swinkels et al., 2000). Errors may be small because some of the "target" positions were in the outer range (towards end-range), where stressing of the joint or periarticular structures, stimulate afferents that contribute to position awareness (Grigg, 1994). Increased afferent information from these receptors might therefore compensate for any position awareness error that arises from trunk muscle dysfunction.

In participants with LBP, any position awareness deficits resulting from trunk muscle dysfunction, would be expected to be most evident through the physiological range, particularly in mid-range – around the neutral spinal posture – where joint and periarticular receptors have less influence on positional awareness (Proske et al., 2009). A later study to be found in Chapter 4 was subsequently designed avoiding end-range "target" positions, to investigate whether errors in position awareness were greater in mid-range and in people with LBP, when dysfunction in trunk muscles may have occurred in response to LBP.

3.6.1.1 Returning to the neutral sitting posture

It was noted during testing, that a large number of participants had difficulty in returning to the "neutral" sitting posture from a flexed position (both people with and without LBP), with participants with LBP appearing to tend to return to a more extended lumbar position. This was only an observation and warrants further investigations.

It was hypothesised that as the segmental muscles of the low back are densely populated with muscle spindles (Amonoo-Kuofi, 1983), along with TrA (Kokkorogiannis, 2004), they will provide the primary sensory information that signal lumbar spinal position in the middle range of sagital spinal movement e.g. the “neutral” sitting posture, when less sensory information is available from joint and ligament structures. These muscles can become dysfunctional with LBP (Hides et al., 1996; Hodges et al., 1996), resulting in possible impairments of position sense, in the mid-range of spinal movement, and poor ability to discriminate the “neutral” sitting posture. When attempting to return the spine to “neutral” from a slumped sitting position, coarser activity of the global muscles such as erector spinae could have resulted in participants extending beyond the “neutral” sitting posture, due to the lack of fine control provided by the deep trunk muscles.

Interestingly, if a muscle spans more than one joint, this can reduce its spindles’ ability to sense movement (Sturnieks, Wright, & Fitzpatrick, 2007). This was investigated however, in the arm and was not a test of position sense, but of movement sense. Whether this would occur similarly in the low back and whether it would affect position sense, as well as movement sense, is yet to be determined. It is considered likely, that as the more superficial back muscles, such as erector spinae, span multiple spinal segments, and in addition, are more sparsely populated with muscle spindles than deeper segmental muscles, their spindles are less likely to provide information on proprioceptive acuity. These observations and hypothesis warrant further investigations

Similar deficits in position sense, when returning to the “neutral” sitting posture occurred however, in participants with NLBP, although the error in participants with LBP was greater, but these differences were non-significant. These small (non-significant) differences could be due to day-to-day variations in measurements. This trend should be further investigated to see if the sedentary nature in some occupations, or the manual work occurring during a normal working day, alters normal

muscle recruitment patterns, potentially causing impairment of lumbar position awareness around the neutral sitting posture. It is perhaps more likely that people with LBP, with ultrasound evidence of multifidus muscle wasting and altered activation of the deep trunk muscles like TrA and multifidus (Hides et al., 1994; Hodges & Richardson, 1999; MacDonald et al., 2009), will show greater deficits in position sense, than people with or without LBP who have normal cross-sectional size of multifidus and deep trunk muscle activation (see section 1.2.2). The use of ultrasound and measures of muscle activation should be considered in future similar studies, and include measurements of all the trunk muscles (deep and superficial), where possible.

As the study was not designed to investigate within-group changes in position sense before and after-work, the after-work test was performed on a different day. This was because the priority in the after-work tests was to ensure participants undertook a full day's work and that there was minimal time delay between completion of work and the after-work data collection. A full working day would not have been possible if testing before and after-work had occurred on the same day.

There was also: (1) a fear that repeated testing on the same day could have aggravated LBP symptoms; (2) logistically testing early morning and evening on the same day was not practical as participants would have found it hard to give up any more of their time on a single day; (3) a practice effect would be possible, with potential improvements in reposition error in the after-work tests, due to the closeness in time between the before- and after-work tests.

In an attempt to minimise possible diurnal variations in position awareness, testing before-work took place between 07.30 and 09.30am and after-work testing took place between 4.00 to 7.00pm. Although diurnal variations in range of low back movement due to time have been found (Dvorák et al., 1995), the results of this study suggests that similar diurnal variations in position sense do not exist, when using the position sense tests utilised in this study.

In both LBP and NLBP groups, there were a number of days between before- and after-work testing. This was for pragmatic reasons and was due to the availability of the participants for testing. It is however unlikely that the small difference in days between groups would have affected the results. Unfortunately, it is not known what the participant's self-reported disability and pain scores were on the days between the before- and after-work tests, as the questionnaires were only completed on the test days and the questions only refer to that specific day. As LBP is variable, acute exacerbations could have affected the comparisons. This is unlikely however, since most participants had relatively minor problems (low disability and pain scores) that were reasonably stable, and when asked, only one participant reported an unrelated acute exacerbation between testing sessions, which had resolved.

3.6.2 Position awareness at the elbow

It is unlikely that a global difference in proprioceptive acuity existed in either group of participants that would affect interpretation of these results, as no significant differences were found in reposition error in the elbow, between participants with and without LBP. It also suggests that there were no differences in short-term memory between groups, and therefore no obvious differences in central processing of proprioceptive information (Gill et al., 1998). If any differences had been found in position sense in the low back between people with and without LBP, the finding of no difference at the elbow would have implied the differences in the low back to be more likely associated with a local problem in the low back, rather than differences in the processing of proprioceptive information at higher levels in the CNS. The elbow was used to test for a global problem with proprioceptive acuity, because its location in the upper limb makes it unlikely it would be affected by decreased sensorimotor function in the low back, and it has a large, observable and easily-measureable range of movement.

3.6.3 Test-retest reliability of position awareness tests

The basic idea behind the context of reliability is that it is an index of the extent to which measurements of participants on different occasions, reveals similar results (Streiner et al., 2008). Data were collected under the same conditions on a different day.

The difference in mean error scores in degrees between day 1 and day 2, for people with and without LBP, were small for all position awareness tests. These small differences may in part be a reflection of the small measurement errors shown during in vitro testing in Chapter 2 (see section 2:4). Both ICCs and Bland and Altman are presented because in studies of reliability, if used alone neither provide a full analysis, and both are appropriate when there are two repeated measures (Rankin et al., 1998).

The small differences in mean error scores between day 1 and day 2 were also shown in the mean differences for Bland and Altman for both people with and without LBP. The values for the 95% limits of agreement were smaller for the position awareness test-retest data for random “target” position in low back flexion and extension in standing and sitting, larger for the return to neutral in standing and much larger for the return to neutral in sitting. This may be a reflection that it was much harder for all participants (pain and non-pain) to identify positions that were near to mid-range of sagittal movement. It may also be due to the emphasis placed by the researcher during testing on participants finding the through range target positions in standing and sitting, rather than returning to the same neutral start position.

For ICCs, formulae (3,1) was used because each participant was rated by the same rater i.e. a single investigator was the only one of interest in this study. This rater was therefore fixed and the reliability reflects the accuracy of this rater only. The results cannot therefore be applied generally to how other raters may perform. The decision to choose ICC (3,1) was also based on the future application of the testing procedure.

Testing throughout this thesis was performed by the same individual who did the reliability testing in this study, therefore ICC (3,1) is the choice (Rankin et al., 1998).

The ICC coefficient values vary ranging from -0.01 to 0.73 and the 95% CIs for ICCs were wide. The actual true ICC coefficient value for each test could lie anywhere between the wide ranges shown by the 95% CI values. This suggests uncertainty as to the true reliability of each of the tests (as measured by ICCs). The ICC coefficient values were disappointingly low for some of the tests, but were consistently better in the people with LBP; however ICCs give no indication of the size or clinical importance of the difference between measurements. They should therefore be interpreted with reference to the raw data and complimented by Bland and Altman 95% limits of agreement tests (Rankin et al., 1998).

In contrast, the mean differences between day 1 and day 2 in all the tests, and the 95% limits of agreement for all but one of the tests, were smaller for people without LBP. The mean error values for all participants remained very low in the vast majority of participants and the differences between individual participants between day 1 and day 2 were very low and similar to the small measurement error shown in the electrogoniometer in Chapter 2 (see section 2.4).

This contrast between the raw data, Bland and Altman tests and ICCs may in part be due to the “target” positions been random and therefore different from day 1 to day 2, and also the lack of a fixed position for the “neutral” position of the low back. Regardless of this however, the actual differences in mean error values measured in degrees between day 1 and day 2, remained very small as previously indicated.

In addition, ICC coefficient values are low in some of the position awareness tests, because the smaller the range of data points on a scale, the lower the ICC will be, and vice-versa (Müller et al., 1994). The data points (mean error values) are similar for all participants;

therefore with such a small range of mean error values, the ICC results are predictably lower. This is a limitation of ICCs and reinforces the view that the coefficient values need to be interpreted with reference to the actual mean error values. They should not detract from the small differences in mean error found on testing between day 1 and day 2. When reporting either ICCs or Bland and Altman tests, perhaps studies similar to this need larger population samples than ten participants in order to be able to confidently interpret the results of analysis. It is suggested the more participants the better, although a sample size of 50 is likely to be sufficient (Streiner et al., 2008).

3.6.4 Limitations of the study

This is the first study to look at position awareness in the low back before and after a shift of work in workers with and without LBP, and in different occupational sub-groups. Unfortunately, several limitations affect our ability to draw clear inferences from the results.

Difficulties with recruitment

The main limitation occured when considering the secondary analysis of occupational sub-groups, as the sample size was too small to enable drawing strong inferences from the findings. Only the sedentary group achieved the sample size required for power. In manual workers and drivers there were discrepancies between the sizes of the sub-populations, so confidence in extrapolating findings for these occupational groups is limited.

The inability to achieve the required sample size for drivers and manual workers was due to difficulties in recruitment. Initially, recruitment of participants by mail shot and posters in the workplace was successful in recruiting sedentary workers. Recruitment of participants (particularly NLBP sufferers) from driving and manual occupations was far more difficult. A major cause of slow recruitment of drivers was probably due to them being self-employed and this made it difficult for them to attend for testing, as it impacted upon their income. A major cause of

lack of recruitment in manual workers was probably due to the lack of industries locally, with a bias towards sedentary work in the local economy.

Recruiting participants with NLBP proved additionally challenging, because as they had never had back problems, they had no health incentive to participate. In addition, because LBP is so prevalent identifying participants without LBP is difficult.

Due to lack of further recruitment from the mailshot and posters, a newspaper advert was published in the local evening newspaper and free newspapers, as well as a radio interview broadcast on local BBC Radio. The newspaper adverts proved to be a very successful method of recruitment, but were expensive and money had to be found from within the limited resources of the grant, which prevented additional advertisements.

When the money for advertisements had run out, the recruitment period was continued for a further 3 months, but only a small number of suitable participants responded to the continued mail shots and posters during this period. Due to continued poor response, recruitment was ended 31st July 2003. This experience in recruiting participants was useful for future studies, as the preferred method of recruitment in the remainder of the thesis was by newspaper advertisement with the cost covered by dedicated funding within a research grant award.

Disability and pain scores

The disability and pain scores of the participants with LBP on the days of testing were low, indicating they were not severely affected at the time of testing. This sample may be representative of the community population with LBP who cope with it relatively well. They are probably unrepresentative of people with more severe LBP, in whom error in spinal position awareness, and its attendant problems, may be greater. On reflection a minimum criterion for RDQ on the day of testing could have been set. It is suggested that on entering a study if the RDQ

score is less than 4, then its ability to detect meaningful improvements is limited (Stratford et al., 1996). A minimum entry criterion of 4 points on the RDQ is therefore recommended for participants entering clinical trials. A score of 4 points on the RDQ could therefore be set as the minimum criterion for participants with LBP in future studies on spinal position sense. Participants would therefore be more representative of patient populations used in clinical intervention studies, making the results more relevant for researchers and clinicians.

Uncertainty also exists about the levels of disability and pain in the preceding weeks or months, because the RDQ and SF-MPQ record levels on the day of testing. For future studies, rather than relying on reports of LBP and disability soley on the day of testing, it may be useful to also collect information on levels of disability and pain in preceding weeks using other questionnaires such as the Aberdeen Low Back Pain Scale (Ruta, Garratt, Wardlaw, & Russell, 1994) and the modified Graded Chronic Pain Scale (GCPS) (Underwood, Barnett, & Vickers, 1999). This would help in finding a population more representative of people with more severe LBP, in whom error in spinal position awareness, may be greater.

It is also acknowledged that there is likely bias in recruitment to studies of this nature, as people who are fear-avoiders are unlikely to volunteer. It is perhaps not surprising therefore that the scores for disability and pain were relatively low and that people with less LBP are more likely to have engaged in the research. An entry criterion with a minimum score for disability and/or pain scores on the day of testing or in the preceding weeks would be helpful in in ensuring that those participants who are minimally affected by their LBP are not included in studies.

In addition, the population of people with LBP were primarily those whose episodes of LBP were less than 12 weeks duration. Only two participants with LBP had a history of an episode of LBP lasting greater than 12 weeks. The participants in this thesis therefore did not have

persistent chronic LBP as defined by European Guidelines as LBP persisting for at least 12 weeks (Airaksinen et al., 2006). It is possible that a population of people with more persistent LBP may have had greater errors in position awareness (see section 6.4.3 for discussion related to the differences in definition and terminology used in studies when describing people with LBP).

Heterogeneous population of people with LBP

The heterogeneous nature of the LBP in the patients in this chapter is a possible limitation. In comparison, a study that identified a homogeneous specific population of people with LBP found significant differences in spinal position awareness between participants with and without LBP (O'Sullivan et al., 2003). Classification of people with LBP into sub-groups would enable this to be investigated further. Unfortunately in this current study, this was not possible and also the specific diagnoses were unknown, therefore preventing retrospective analysis of position awareness based on sub-classification of the participants with LBP.

Location of data collection

Although the working day did not impair low back position awareness, difficulties in logistics and the desire to have a consistent testing environment for all participants meant testing could not be performed at their place of work. Therefore, drivers might have been assessed after they had just finished driving, however sedentary and manual workers had travelled from their work place. This is an important consideration for designing future studies investigating position sense after exposure to occupational risk factors such as prolonged sitting or manual work.

It is possible, that if any work-induced changes in the static and dynamic responses of Golgi tendon organs and muscle spindles (Graham et al., 1986; Hutton et al., 1986; Lagier-Tessonnier et al., 1993), and in the back extensor muscles (Biering-Sørensen, 1984; Mannion et al., 1997a; Roy et al., 1989; Suzuki et al., 1983; Taimela et

al., 1999) had occurred in the participants, these changes are likely to have been transient and most easily identified during exposure, or immediately after exposure, to the risk factor. This may be why prolonged flexed sitting posture was found to impair spinal position awareness when NLBP participants were tested immediately on completing a timed sitting task in a laboratory setting (Dolan et al., 2006).

Further studies in the laboratory setting, or on site at the workplace, should investigate whether similar findings would occur in people with and without LBP during or immediately after exposure to sitting or driving at work, or manual work. This could be investigated immediately at the end of a full day of sitting at work or repetitive manual work, and subsequently in participants immediately after they undergo a standardised protocol related to time at work, involving prolonged sitting or physical work under experimental conditions. These further studies could therefore investigate whether any impairment in spinal position awareness are time dependent, as poor responses to sudden loading and movement, and potential injury and pain, may be more likely to occur over a specific time period following the task.

The study in this chapter, suggests that if position sense deficits were to be found immediately after exposure to risk factors like sitting, the recovery in position sense in humans occurred within an hour – the maximum time between participants' completing their work and testing. Unfortunately, the exact length of time between end of work and testing, and when during the day participants were exposed to specific risk factors, was unknown. A specific period of for example, slump sitting or manual work (e.g. 20 minutes) immediately prior to testing would therefore have been a useful addition to the protocol.

Animal studies have suggested that multifidus muscle activity can take over 7 hours to recover following 20 minutes of static lumbar flexion stretch that caused 12-15mm displacement to the L4/5 supraspinous

ligament in the cat spine (Jackson, Solomonow, Zhou, Baratta, & Harris, 2001) and 20 minutes of static and repetitive flexion loading at between 20 to 70 N, causing approximately 10-28mm displacement to the feline L4/5 supraspinous ligament (Solomonow et al., 2003). It is suggested that both types of exposure, cause an initial loss in muscle activity and subsequent micro-damage to soft tissues, eliciting muscle spasms, followed by initial and delayed muscle hyperexcitability (Solomonow et al., 2003). Interpreting the findings of this animal study into humans is difficult. The level of stretch may be an important factor and needs standardising. In addition, the static and repetitive flexion loading performed in the cat is difficult to relate to functional tasks in humans. Investigating whether similar alterations in muscle activity of the deep trunk muscles occurred in humans after exposure to static low back flexion following prolonged slump sitting posture, is recommended. As these muscles have a rich supply of muscle spindles (Amonoo-Kuofi, 1983), they provide the CNS with information on position sense. Any alteration in the activity in these muscles may affect the results of position sense testing and is worthy of investigating for possible differences in position sense in people with and without LBP.

Use of electrogoniometer

Although electrogoniometers give minimal cutaneous feedback they are unable to prevent skin movement. Studies however, have shown measurement of spinal movement with skin markers is valid (Gracovetsky et al., 1995). The accuracy of the electrogoniometry equipment was recorded in mean degrees of error, for ease of comparison, to the primary unit of measure (i.e. degrees), used throughout this thesis. The results in Chapter 2 demonstrated that the electrogoniometer equipment itself was accurate to within a range of 0 to 0.40 degrees of mean error, for through range testing between +/- 60 degrees, and between 0 to 0.5 degrees of mean error for signal stability testing, between +/- 60 degrees. This was considered an acceptable level of accuracy and is comparable to other equipment that could have been used. They are similar to the results of Rowe et al., (2001) who showed the electrogoniometer was accurate to within 1 to

2 degrees across ranges up to -120 to +120 degrees (in relative terms, this is between 1% and 1.5% of the measuring range). The mean errors in position sense, found in both LBP and NLBP participants before and after a shift of work, were well in excess of the maximum mean errors found in the electrogoniometer equipment itself.

At data collection the researcher was not blinded to whether the participant had back pain or not. The recording of the data by the electrogoniometer however, was automated as was the data transfer process into a SPSS database. Subsequently, an independent person coded LBP and NLBP groups, so that the researcher remained "blinded" to participants back pain status during data analysis (see section 3.4.7.2).

Motion of the spine

Finally, although position sense was reported in the sagittal plane, it is acknowledged that the spine does not just move in a single plane. Motion occurs in multiple planes and translations, and analysis of these would provide more accurate information on proprioceptive ability. A similar observation however, was made to Rowe et al., (2001), in that errors can become substantial if the electrogoniometer moves excessively in another plane at the same time e.g. during side flexion or rotation. Associated side flexion movements of greater than 40 degrees and rotation of 60 degrees are considered problematic, but if associated movements like rotation are less than 20 degrees, errors due to "crosstalk" are small (Rowe et al., 2001). This "crosstalk" (Jonsson et al., 2001), would effect the validity and reliability of the electrogoniometer and was consequently avoided during testing on people with and without LBP in this thesis. Therefore to minimise the potential for measurement error, it was considered important that movements in the sagittal plane were investigated and movements in other planes avoided, giving greater confidence in the results found in the studies in this thesis. Once baseline data are collected on sagittal plane movements, further work could be undertaken to determine the involvement of other planes of movement in low back position sense.

These could be measured individually or collectively with all spinal movements, if the potential for “crosstalk” could be minimised.

The testing procedures used in this thesis were therefore designed to avoid “crosstalk”. The electrogoniometer was visible for all movements in all participants and no obvious side flexion or rotation occurred and certainly none that would have affected the accuracy of the electrogoniometer. Variations in side flexion position during forward and backward movements of the low back were observed for, but found to be less than a degree in most participants. Other apparatus like the Fastrak measures anteriorposterior translation movement (in centimetres), as part of its calculation of position sense error (O'Sullivan et al., 2003), but these translation measurements were found to be small. Similarly, as translation and rotation movements in the low back are small (Bogduk, 1997) any errors recorded, may not have exceeded the error in the testing equipment.

Therefore, as the electrogoniometer is easy to use for the participant and researcher, it takes relatively little time to set-up, is accurate and relatively inexpensive, it was felt the benefits of its use outweighed any slight measurement error from cutaneous feedback from the sensor or from “crosstalk”.

It is also acknowledged, that the electrogoniometer needs to be carefully handled to avoid damage. The accuracy data reported in Chapter 2 are the results obtained at the end of all testing for all studies, so as to demonstrate that if handled carefully the equipment remains accurate even after significant use.

3.6.5 Implications of the research

As far as could be determined, this study was the first to investigate position sense in the low back in a large sample at the beginning and end of a working day, and in sedentary workers.

As there is no evidence of sensorimotor changes, when testing the ability to locate target positions, clinical implications are restricted. Testing position sense in the low back, using the method in this study of asking patients to reproduce random target positions through range (middle to outer, but avoiding end-range), would not appear to be a useful clinical tool for investigating potential differences in proprioceptive acuity between people with recurrent NSLBP and without LBP, or at least within this particular population of people with LBP.

The results however, do have some limited use for clinicians as position sense does not appear to be affected by the time of day i.e. between 07.30 and 09.30am and 16.00 and 19.00pm when testing occurred. This is useful knowledge for clinicians as they will not have to see patients at consistent times of the day, when comparing measures of low back position sense.

With the research findings in this study showing that the greatest reposition errors occurred when returning to a neutral spinal posture, a development would be to investigate position sense only in mid-range. A later study in Chapter 4 was designed to investigate this.

In addition, a development would also be to investigate position sense in relation to where people perceive a “good” sitting posture is located, and its relation to end-range extension and flexion in the low back. This is in contrast to finding a neutral upright posture that was located with the help of the researcher if needed, as occurred in this study. It is possible that altered motor programming, due to LBP, may result in this perceived “good” sitting posture been located differently in people with and without LBP. A later study in Chapter 5 was designed to investigate this.

The data from this study therefore, specifically in relation to position awareness when returning to the "neutral" spinal posture in sitting, were used in the sample size calculation for the studies in Chapters 4 and 5, which investigated position awareness when locating target positions in mid-range in sitting and for locating a "good" sitting posture (see section 4.4.4).

3.7 Summary of findings

- *Before-work and after-work*
- No differences were found in the accuracy of low back position awareness between participants with and without LBP.
- Greatest reposition errors were evident in participants with and without LBP when returning to the neutral sitting posture.
- A trend was noted that before-work the greatest reposition errors were evident in participants with LBP compared to NLBP when returning to the neutral sitting posture.
- Sedentary occupation did not have any effect on low back position acuity. Unfortunately, uncertainty exists about the effect of occupation on position sense in manual and driving workers, as the sample sizes in these occupations were too small.

4 LOW BACK POSITION AWARENESS IN MID-RANGE OF MOVEMENT FROM SLUMP TO EXTENSION IN SITTING

4.1 Background

The study in Chapter 3 found no evidence of any difference in low back position sense between two groups: people with or without back pain. The participants in both groups however, found it harder to locate a "target" position around the mid-range of sagittal plane movement in sitting i.e. to locate the neutral sitting posture, compared to "target" positions towards outer-range of movement.

To be able to appreciate and maintain a neutral upright sitting posture located in mid-range of low back movement, accurate sensory feedback from, and activation of, appropriate trunk muscles are essential (Cholewicki, Panjabi, & Khachatryan, 1997; Holm, Indahl, & Solomonow, 2002). In this posture, high concentrations of muscle spindles in the deep trunk muscles (Amonoo-Kuofi, 1983; Kokkorogiannis, 2004) provide vital sensory information, that signals lumbar spinal position and are responsible in part, for spinal stability (Bergmark, 1989). If these muscles are dysfunctional, due to LBP and damage (Hides et al., 1996; O'Sullivan et al., 1997b), this might impair position awareness in the mid-range of spinal movement, resulting in poor ability to discriminate and maintain the neutral spinal posture. This might explain why there was a trend for greater errors to be found when returning to the neutral sitting posture in participants with LBP, although only before work.

The importance of an erect posture is supported by a biomechanical modelling study, emphasising the stability role of low back muscles and their ability to decrease loading on ligaments, discs and the vertebral bodies (Goel et al., 1993). The stabilising function of trunk muscles is vital in mid-range of low back movement around the neutral spinal

posture, where the spine is less stiff and vulnerable to buckling (giving way) under compressive loading (Cholewicki et al., 1997). Any dysfunction of trunk muscles, due to LBP, would adversely affect their ability to control the neutral posture and decrease stability of the spine, due to a loss of vital sensory information on spinal position and resultant inappropriate motor responses, during static and dynamic postures.

Control of the lumbar lordosis also reduces the compressive stress in the spine (Gracovetsky, Kary, Pitchen, Levy, & Ben Said, 1989) and minimises end-range loading of pain-sensitised spinal tissue (O'Sullivan et al., 2003). Therefore, improving the ability of patients with LBP to appreciate mid-range low back sagittal movement around the neutral position and to control the lumbar lordosis during static and dynamic postures, might be an important aspect in managing LBP. The study described in Chapter 3 was not designed to primarily investigate position awareness around the neutral posture. As poor ability to attain and maintain the neutral lumbar posture in participants with LBP has previously been reported (Hamilton & Richardson, 1998; O'Sullivan et al., 2003), research elucidating the importance of the neutral spinal position is warranted.

Aim:

The aim of this study was to investigate whether people with recurrent non-specific low back pain had greater difficulty accurately discriminating low back position sense in mid-range of sagittal plane movement in sitting, than people who have never reported back pain.

The study also investigated the test-retest reliability of data for the position awareness test.

4.2 Null hypothesis

4.2.1 Primary null hypothesis

There is no difference in low back position sense around mid-range of forward and backward movement of the low back, between people with recurrent non-specific low back pain and people who have never reported low back pain.

4.3 Methodology

A quantitative approach was used to compare position awareness between people with and without LBP, with reposition error the quantitative value for comparison (Gill et al., 1998; Newcomer et al., 2000; O'Sullivan et al., 2003) measured in degrees using a flexible M180B electrogoniometer (Biometrics Ltd, Gwent, UK) (Figure 2:1).

4.4 Methods

4.4.1 Design

A cross-sectional study design was chosen to observe position awareness at a point in time in two samples - with and without LBP. Because measurement of position awareness was not carried out before and after the onset of LBP, the design cannot prove a cause-effect relationship. Instead, the findings would be used to generate hypotheses to be investigated in future studies.

4.4.2 Ethical approval and research governance

Ethical approval was given by the Southampton & SW Hampshire LREC (LREC number: 07/Q1702/52). A copy of an approval letter is shown in Appendix 4:1. The University of Southampton acted as the sponsor for the research.

4.4.3 Participant profiles and entry criteria

People with and without recurrent non-specific LBP were recruited (for details on recruitment see 4.4.5). General information and adherence to the entry criteria below were determined by the researcher over the telephone with participants, prior to their inclusion in the study and confirmed if they attended for testing.

4.4.3.1 Participants with low back pain

- Participants aged between 18-60 years. An upper age limit of 60 years was chosen to minimise the possibility of participants having age-related decreases in position sense, which occur from the mid to late sixties (Hurley et al., 1998a; Pai et al., 1997).
- Participants with LBP had recurrent non-specific LBP defined as:
    - pain between the lowest ribs and gluteal folds (Smedley et al., 1997)
    - with or without referral into the legs
    - LBP not attributable to a recognisable, known specific pathology i.e. several structures may contribute to the LBP, such as the joints, discs and connective tissue (Airaksinen et al., 2006; NICE, 2009; van Tulder et al., 2006)
    - a painful episode in the previous 3 months lasting greater than 24 hours (Smedley et al., 1997)
    - previous history of at least one other episode of LBP (Little et al., 2008) lasting greater than 24 hours
    - and at least one episode in the past that has necessitated medical advice on at least one occasion.

These criteria aimed to ensure participants had experienced LBP of sufficient seriousness that it was potentially more likely to affect sensorimotor function than e.g. transient LBP of short duration and occurring 6 months previously.

4.4.3.2 Participants without low back pain

Participants aged 18-60 years, who had not reported even minor LBP within the last 12 months, with no history of LBP lasting longer than 24 hours that had necessitated a period off work, bed rest or health care attention and intervention of any sort, and no injuries to their lower back. These criteria were to minimise the possibility of sensorimotor function being affected due to age or previous minor episodes of LBP.

4.4.3.3 Exclusion criteria

Participants (LBP and NLBP) were excluded if they demonstrated any of the following:

- inability to perform the movements required for the proprioceptive tests.
- severe LBP on the day of testing - a score of greater than 8 out of 10 on the modified Graded Chronic Pain Scale (GCPS) (or known as the modified Von Korff scales) (Underwood et al., 1999; Von Korff, Jensen, & Karoly, 2000; Von Korff, Ormel, Keefe, & Dworkin, 1992). This cut-off point was a pragmatic decision based on clinical experience. If pain was too high, it was felt participants might not be able to complete the test movements and their pain could be aggravated, leading to potential concerns from the Local Research Ethics Committee. Extreme levels of pain were therefore avoided, in an attempt to decrease the likelihood of this occurring.
- inability to complete the questionnaires e.g. due to language or understanding of the questions even after explanation by the researcher.
- unstable co-existing rheumatological, cardiovascular, respiratory, neurological, psychiatric or psychological disorders or medical conditions that might affect balance and sensorimotor function such as Ménière's disease, vertigo, vestibular disturbances. The aim was to mitigate the possibility of participants being unable to perform or complete the testing, or to have medical conditions that may affect sensorimotor function.

- use of systemic steroids or anticoagulants. Although unlikely, this was felt necessary to minimise the potential for pain or soreness as a result of performing the test movements.
- surgery to the back, pelvis or head as these had the potential to affect sensorimotor function.
- progressive nerve root signs and symptoms; cauda equina symptoms; non-mechanical pain (a pain not affected by movement or position). These symptoms suggested more severe pathology requiring specific medical assessment or treatment and could have been easily aggravated by testing.

4.4.4 Sample size

Logged data, related to returning to a neutral sitting posture from the study in Chapter 3, were used in the sample size calculation (Phillips, Hurley, & Mullee, 2005). A sample size of 100 participants in total (50 in each group) was calculated to have 90% power to detect a difference in means of 0.405 (the difference between a Group 1 mean, $\mu 1$, of 1.388 and a Group 2 mean, $\mu 2$, of 1.793), assuming that the common standard deviation is 0.614 using a two group t-test with a 0.05 (5%) two-sided significance level (Lemeshow et al., 1992). When comparing between groups on the original data scale, i.e. in degrees (Altman, 1991), the mean difference of 0.405 equates to two degrees difference between a non-low back pain (NLBP) Group mean reposition error of 4.0 degrees and a LBP Group mean reposition error of 6.0 degrees. A 2.0 degree difference is considered clinically meaningful, based on the knowledge that spinal position as little as 2 degrees from the neutral spinal posture substantially increases axial compressive loading stress on the spine (Kiefer et al., 1997).

4.4.5 Recruitment

Recruitment and testing took place between February and October 2008. Participants with LBP were invited by the researcher to participate from patients attending out-patient physiotherapy in local Primary Care Trusts, physiotherapy departments in private hospitals, private physiotherapy clinics, GP practices and pharmacies. In addition, posters and adverts were placed in the local evening press and weekly free newspapers, and workplace publications at the University of Southampton (Appendices 4:2, 4:3a & b, 4:4a & b, 4:5a & b). Any patients attending for treatment who were potentially interested in volunteering were given the cover letter and information letter by the physiotherapist, GP or pharmacist or they were asked to contact the researcher who sent the information letter by email, fax or post (Appendices 4:6, 4:7a & 4:8). Those patients responding directly to posters or adverts were sent the cover letter and information letter by the researcher via email, fax or post.

Participants without LBP were recruited via posters and adverts in the local press, and workplace publications (Appendices 4:3a & c, 4:4a & c, 4:5a & 4:5c). Interested participants contacted the researcher, who sent the cover letter and information letter by email, fax or post (Appendices 4:6, 4:7b).

All potential participants were given the opportunity to read the information sheet and discuss it with relatives, friends and the researcher before participating in the study. All interested participants were telephoned by the researcher and asked to confirm their eligibility including their occupation status prior to participation (Appendix 4:9). Eligibility was reconfirmed by the researcher when the participants attended for research testing at a dedicated research room at the School of Health Sciences (now Faculty of Health Sciences), University of Southampton. It was explained by the researcher that participation in the research project was entirely voluntary, and that they could withdraw from the study at any time without giving a reason and without prejudice.

To facilitate recruitment and ensure participants were not financially disadvantaged, their time / travel expenses were reimbursed at £25 per visit a predetermined level agreed by the Ethics Committee.

4.4.6 Data collection procedure

4.4.6.1 Clinical examination

Each participant was telephoned by the researcher and demographic details obtained including: details of occupation; age; weight; height; number of hours exercising per week; plus their medical history and back problems, e.g. years since onset of LBP, the average duration of recurrent episodes of LBP and previous management (Appendix 4:9). Eligibility for entering the study was established by the researcher when participants attended for testing, to ensure no participant changed from having no LBP to now reporting LBP. Written consent was attained prior to participation and was taken by the researcher when the participant first attended for testing (Appendices 4:10a & 4:10b).

4.4.6.2 Self-administered questionnaires

Participants then completed self-administered questionnaires related to their back pain (Appendices 4:11, 4:12 & 4:13), prior to testing their reposition awareness. In addition, participants without LBP were required to complete these questionnaires to ensure they had remained asymptomatic.

Disability

Disability was assessed using the Roland Disability Questionnaire (RDQ) (Appendix 4:11) to investigate whether there was an association between disability and errors in position sense. This questionnaire was chosen because it is valid, reliable, self-completed, short, simple to use and is widely recommended for assessing physical function in LBP and in particular people with mild to moderate disability (Bombardier, 2000; Roland et al., 2000), similar to the participants that were anticipated to

be recruited for this study, based on the previous recruitment experience in Chapter 3.

In the study described in Chapter 3, the modified version of the RDQ was used (Patrick et al., 1995). The modifications were designed to improve the responsiveness of the original RDQ to clinical changes over time (Patrick et al., 1995). In this study however, no responsiveness to clinical change was required (unlike in a randomised clinical trial), as the measure of disability was a point in time measure. The original version of the RDQ was therefore preferred, and because of its recommendation over the modified version and continued widespread international use (Roland et al., 2000), allowing for easier comparison with findings reported in the literature. On reflection, the original version of the RDQ could have been used in the study in Chapter 3.

The original version of the RDQ has 24 questions, each scoring 1 point if ticked, and the higher the score, the greater the disability due to LBP. The RDQ is reported to have good validity, reliability and responsiveness (Garratt, Klaber Moffett, & Farrin, 2001). Test-retest reliability has been reported for the same day (correlation coefficient 0.91; agreement % coefficient satisfactory at 0.83) (Roland & Morris, 1983) and over 3-weeks (Pearson's r range from 0.69 to 0.87) (Deyo, 1986). Construct validity has been described by correlating with patient characteristics. It is considered as reproducible and valid as the Sickness Impact Profile (SIP), with high correlations between the RDQ and the SIP (Pearson's r 0.85) and particularly with the physical dimension of the SIP (Pearson's r 0.89) (Deyo, 1986). As the RDQ focuses on a limited range of physical function this is considered a strength in its content validity (Roland et al., 2000). In assessing validity versus other measures of disability, the RDQ is also reported to correlate well with the Oswestry Disability Index (Pearson's r range 0.66 to 0.72) (Leclaire, Blier, Fortin, & Proulx, 1997), physical sub-scales of the SF36 (Roland et al., 2000) and the Quebec Back Scale (r = 0.77) (Kopec et al., 1995). The RDQ is also reported to have good psychometric properties, in terms of internal consistency (ICC range

0.86 to 0.93; Cronbach's alpha range 0.88 to 0.90) (Kopec et al., 1995) and responsiveness (Roland et al., 2000; Stratford, Binkley, Solomon, Gill, & Finch, 1994).

As the RDQ reports the level of disability on the day it is completed, the Aberdeen Low Back Pain Scale was also used, so as to gain greater understanding of disability levels in the preceding two weeks (Appendix 4:12). Similarly to the RDQ, it is reported to have good validity, reliability and responsiveness (Garratt et al., 2001; Ruta et al., 1994), and is internally consistent (Cronbach's alpha 0.8) and has good test-retest reliability (correlation 0.94) (Ruta et al., 1994). There is moderate to strong correlation to the RDQ (0.68) (Garratt et al., 2001), moderate to weak correlation with the SF-36 (range 0.36 to 0.69) and EuroQol (0.44), work loss (0.26), GP visits (0.23) and pain (range 0.24 to 0.25) (Garratt et al., 2001; Ruta et al., 1994). Its responsiveness (standardised response mean (SRM) 0.62) (Ruta et al., 1994) (SRM range 0.57 to 1.16) (Garratt et al., 2001) is considered superior to the RDQ (SRM range 0.23 to 0.90), SF-36 (SRM range 0.09 to 0.50) and EuroQol (SRM range 0.06 to 0.51) (Garratt et al., 2001; Ruta et al., 1994). It was used to investigate whether there was an association between recent levels of disability in the preceding 2 weeks and errors in position awareness.

Pain

The severity of LBP, as defined by pain intensity and interference with daily activities, was assessed using the modified Graded Chronic Pain Scale (GCPS) (or known as the modified Von Korff scales) (Underwood et al., 1999; Von Korff et al., 2000; Von Korff et al., 1992). This scale was used to investigate for an association between pain and errors in position awareness (Appendix 4:13). It has been reported that it correlates well with the pain and physical function aspects of the SF-36 (Pearson's r range 0.61 to 0.78) and is internally consistent (Cronbach's alpha range 0.89 to 0.96). The retest data suggests the measures are repeatable and responsive (ICC range 0.74 to 0.96; SRM range 0.02 to 0.80) (Underwood et al., 1999). The modified GCPS version is easily completed, efficient, valid, repeatable and a responsive

tool for measuring LBP and disability over the preceding 4 weeks (Underwood et al., 1999). The modified GCPS was used to give a greater understanding of severity of back pain in the preceding 4 weeks and not just on the day of testing, which was a disadvantage of the SF-MPQ used in Chapter 3. In addition, it was selected for use over the original GCPS, because it recorded the last 4 weeks rather than in the preceding 6 months with the original GCPS. It was therefore anticipated to avoid problems with participant recall, that may have occurred if using the timescale of the original GCPS.

4.4.6.3 Position awareness in the low back

Each participant's spinal reposition sense was assessed by a flexible M180B electrogoniometer (Figure 2:1) (Biometrics Ltd, Gwent, UK) connected by leads to a DataLINK system (Figure 2:2) with management version 2.0 software (see Chapter 2).

Calibration of electrogoniometer prior to test of position sense

Prior to testing each participant, the electrogoniometer was calibrated to 0 degrees and moved through a known angle of 90 degrees and back to 0 degrees to ensure accuracy within a degree of error.

Protocol for estimation of acuity of low back position sense

To enable observation during testing, participants wore shorts and a t-shirt. Low back position awareness was assessed by an electrogoniometer placed over the lumbosacral spine using double-sided sticky tape (Hurley et al., 2000). The electrogoniometer was turned on at least 10-minutes before use to allow its temperature to stabilise as a consequence of heating due to electrical current (Jonsson et al., 2001). Electrogoniometer placement was as described in section 3.4.6.3. The researcher attached the upper part of the lower arm of the electrogoniometer on the lower aspect of the S1 spinous process and the lower part of the upper arm of the electrogoniometer was placed on the upper aspect of the L1 spinous process.

The researcher took all measurements on all participants, to ensure consistency with testing procedures. Participants were told that the test

movements should not reproduce LBP and if this occurred, they were to stop and report it to the investigator.

Participants were asked to sit towards the edge of a slightly-raised couch with their hips and knees at 90 degrees and their feet just off the ground. This was in contrast to Chapter 3 where participants were sitting with their posterior thighs in contact with the couch and their feet in contact with the floor. This was to minimize extraneous sensory cutaneous input from the back, thighs and feet. It was anticipated decreased sensory cutaneous input, might make it harder during position sense testing for all participants.

In an attempt to aid consistency of the testing procedure between participants, they were required to start at end-range of flexion in a position of slump sitting (Figure 4.1). This meant the target positions required greater through-range spinal movement, in comparison to the earlier study in Chapter 3, where there was a neutral start position. It is acknowledged however, that for example the muscle activity required to move through this greater range, may heighten proprioceptive feedback to the CNS, due to increased afferent input to the CNS from muscle spindles (Gandevia et al., 1992), and possibly result in small errors when repositioning (see section 6.7.2).

Starting from a slumped sitting position (Figure 4:1), participants were asked by the researcher to extend their low back slowly. During this movement the researcher asked them to stop at a random “target” position in the middle range of sagittal plane movement. They were asked to concentrate on, and remember this “target” position for 3-seconds (Maffey-Ward et al., 1996), before returning to the slumped starting position. After 3-seconds, each participant was asked to return to the “target” position; the position they returned to - the “reproduced” position - was recorded. They then returned to the slump position. This procedure was repeated for 10 random “target” positions in the mid-range of sagittal plane movement. Ten tests were chosen to ensure stability of a participant’s proprioceptive function and this number have been recommended in other studies testing position sense (Allison et al., 2003; Hurley et al., 1996; Hurley et al., 1998a).

Figure 4:1. Attachment of electrogoniometer and low back slump start position in sitting

To prevent visual feedback, participants kept their eyes closed during the location of each “target” position and when reproducing this position. They were allowed to open their eyes between the 10 tests. This was a change to the previous methods in Chapter 3 when a blindfold was used throughout testing. The change was in response to a recommendation made by a blinded reviewer, who read the grant application for this research. They suggested that participants be allowed to open their eyes between the 10 tests, to enable them to “reset” their perceptual field and minimise attention drift.

Participants folded their arms in front of and away from the body during the location of each “target” position and when attempting to reproduce this position, to prevent feedback on spinal position from contact of the arms with the body. At the end of each random target position test, participants could rest their arms to prevent possible distraction from muscles aching in the upper back and upper limbs.

Following testing, the electrogoniometer was removed from the participant and the skin washed to remove any residue of the double-sided sticky tape. The skin was inspected, but no reactions to the tape were observed.

The absolute error between each “target” and “reproduced” position was calculated in degrees. Reposition error was calculated as a mean of the 10 absolute error values and this was used in the analysis.

Test-retest of position awareness tests

For each of the position awareness tests, test-retest data were recorded for ten people with and ten people without LBP. Data were collected under the same conditions on a different day to allow comparison.

4.4.7 Data analysis

4.4.7.1 Participant data

Means, standard deviation and ranges are given for participant characteristics: age; weight, height and body mass index (BMI). In addition, for participants with LBP the means, standard deviation and ranges are given for self reported disability; pain scores; the length in time of the history of recurrent LBP (years) and the average duration of recurrent episodes of LBP (days).

4.4.7.2 Data processing

Data collected by the electrogoniometer were recorded using the DataLog system. The data were then exported anonymously in ASCII format to a University workstation. Geodata, a computer consultancy company at the University of Southampton, converted all participants ASCII data into degrees. The relevant “target” and “reproduced” positions in degrees were then transferred automatically into a SPSS database by Geodata. An independent person coded LBP and NLBP groups, so that the researcher remained “blinded” to participants back pain status during data analysis. All data analyses were performed using SPSS version 14.0, SPSS version 16.0 and SPSS version 18.0 statistical software (SPSS, Chicago, Illinois, USA). For Bland and Altman tests of agreement for the test-retest data, the data were transferred from SPSS into an Excel spreadsheet. Both SPSS and Excel were chosen for this study and used throughout the thesis, because of their appropriateness and availability through the University and because the researcher had extensive experience in their use.

4.4.7.3 Assessment of joint position sense acuity

The statistical analysis presented, is a stand-alone comparison of low back position sense in participants with and without LBP.
The data point used for analysis for each “target” position was recorded at the end of the 3-second hold, equating to the timing when participants were asked to “remember this position.” Data for the

analysis of each “reproduced” position were recorded when the participant indicated they had found the “target” position.

The absolute error between the “target” and “reproduced” position was calculated in degrees, for each of the 10 reposition tests. The reposition error for each participant, for each test, was then calculated as a mean of these 10 absolute error values. This was taken to be the joint position sense for each participant, with a greater reposition error value indicating poor position sense, i.e. poorer position acuity. The distributions of data were checked by plotting histograms. The average mean reposition error in position awareness, was then calculated for the LBP and NLBP group and compared using a two sample t-test, with level of significance $P < 0.05$. To minimise the possibility of finding a significant result by chance, the level of significance for secondary hypothesis was set at $P < 0.01$ (i.e. a 1% possibility of a chance finding when $P < 0.01$, versus a 5% possibility of a chance finding when $P < 0.05$).

The two sample t-test was chosen for comparing the error in position sense data (measured in degrees) between two groups (participants with and without LBP), and allows for calculation of 95% confidence intervals. It is a “robust” statistical test and appropriate even when the measurement data deviates moderately from the normal distribution (Everitt, 2006).

Correlation between position sense acuity and pain; disability; the number of recurrent episodes of LBP in the past year and the duration of LBP, in all participants with LBP, was evaluated using Pearson’s product movement correlation coefficient (r) (Hicks, 1995). Correlation between position sense acuity and the frequency of regular exercise per week, in all participants, was also evaluated. To minimise the possibility of finding a significant result by chance, the level of significance was set at $P < 0.01$.

4.4.7.4 Test-retest of the position awareness tests

The data are presented as mean error values for ease of comparison. The reposition error for each participant, for each test, was calculated as a mean of the 10 absolute error values (see 4.4.7.3). The results for test 1 and test 2 were compared. The greater the difference in error values between test 1 and test 2, the poorer the test-retest reliability when interpreted using the raw data.

Bland and Altman tests of agreement between measurements that include the mean difference (SD), 2xSD and 95% limits of agreement, and ICC's and the 95% CI for the ICCs are also presented (Bland et al., 1986; Rankin et al., 1998).

For ICCs, the formulae (3,1) was chosen in preference to e.g. ICC (1,1), (2,1) and (1,*k*), (2,*k*) and (3,*k*), because a specific correlation value was calculated from a single position awareness test, and a single rater was used in this study and in the other studies in this thesis (Müller et al., 1994; Shrout et al., 1979):

$$\text{ICC (3,1)} = \frac{\text{subject variability}}{\text{subject variability + random error variability}}$$

4.5 Results

4.5.1 Participant characteristics

In total, 100 participants were recruited to the study, which was the planned number from the sample size calculation (section 4.4.4). Fifty people with a history of recurrent LBP aged between 18-60 years were identified and their low back position sense was compared to 50 participants with NLBP.

The characteristics of participants are presented in Table 4:1. There were more females in both groups. The mean values for participant characteristics were found to be similar for participants with and without LBP, with increased mean weight consistently found in participants with LBP.

Table 4:1. Participant characteristics

		LBP *n=50*	**NLBP *n=50***
Age in years	Mean (SD) Median (range)	46.5 (10.9) 49 (18, 60)	43.6 (11.0) 45 (18, 59)
Male / female		20 / 30	16 /34
Weight in kg	Mean (SD) Median (range)	78.9 (17.1) 79 (53, 127)	72.8 (14.2) 70 (51, 102)
Height in cm	Mean (SD) Median (range)	170.6 (9.7) 170 (152, 196)	170.0 (7.7) 169 (157, 189)
Body mass index (BMI)	Mean (SD) Median (range)	26.4 (5.2) 25.6 (17.4, 44.4)	25.9 (5.2) 25 (17.6, 44.5)
Years since onset of LBP	Mean (SD) Median (range)	15.6 (10.5) 14.5 (1, 45)	
Duration of LBP episodes in days	Mean (SD) Median (range)	7.5 (8.2) 5 (1, 39)	

Footnote: For weight, data from 1 participant with LBP was missing (n=49). For height, data from 1 participant with LBP was missing (n=49). For BMI, complete data from 2 participants with LBP was missing (n=48). For average duration of LBP episodes, 2 participants were unable to specify (n=48).

Self-reported disability (RDQ) and SF-MPQ scores for all participants with LBP are presented in Table 4:2.

Table 4:2. Self-reported disability (RDQ, Aberdeen and modified GCPS), and pain scores (modified GCPS)

		LBP *n=50*
RDQ	Mean (SD) Median (range)	4.9 (6.1) 3 (0, 37)
Aberdeen	Mean (SD) Median (range)	24.3 (14.5) 21.3 (0, 77.8)
Modified GCPS – disability	Mean (SD) Median (range)	29.4 (22.1) 26.7 (0, 80)
Modified GCPS – pain	Mean (SD) Median (range)	35.1 (17.8) 35 (0, 73.3)

RDQ = Roland disability questionnaire
Aberdeen = Aberdeen Low Back Pain Scale
GCPS = Graded Chronic Pain Scale
(SD) = standard deviation

Footnote: RDQ questions relate to the day of testing; GCPS relates to the preceding 4 weeks; Aberdeen Low Back Pain Scale to the preceding 2 weeks. RDQ scores are out of 24; Aberdeen Low Back Pain Scale and GCPS are presented out of 100. The higher the score, the greater the disability.

4.5.1.1 Participant characteristics for test-retest data

The participant characteristics for test-retest data showed slightly higher values for participants with LBP for age, weight and BMI (Table 4:3).

Table 4:3. Participant characteristics for test-retest data

		LBP *n=10*	NLBP *n=10*
Age in years	Mean (SD) Median (range)	51.7 (7.4) 51.5 (41, 60)	47 (7.3) 48 (35, 58)
Male / female		5 / 5	3 / 7
Weight in kg	Mean (SD) Median (range)	74.7 (12.5) 74.5 (55, 94)	71.8 (15) 67 (53, 102)
Height in cm	Mean (SD) Median (range)	167.9 (11.6) 168.3 (152, 185)	168.9 (7.5) 170 (157, 182)
Body mass index (BMI)	Mean (SD) Median (range)	25.9 (4.6) 25.7 (21.1, 31.3)	23.2 (3.8) 21.7 (19.3, 30.8)
Years since onset of LBP	Mean (SD) Median (range)	18.9 (12.5) 21 (1, 45)	
Duration of LBP episodes in days	Mean (SD) Median (range)	7.2 (6.5) 5 (1, 21)	

(SD) = standard deviation

The mean score for self-reported disability (RDQ) for the ten participants with LBP and for SF-MPQ were similar for Day 1 and Day 2 (Table 4.4).

Table 4:4. Self-reported disability (RDQ, Aberdeen and modified GCPS), and pain scores (modified GCPS) for test-retest data (n = 10)

		Day 1	Day 2
RDQ	Mean (SD)	3.5 (4)	3.4 (4.2)
	Median (range)	2.5 (0, 14)	3.4 (0, 13)
Aberdeen	Mean (SD)	21 (13)	22.9 (13.2)
	Median (range)	22.6 (1.9, 37.5)	31.5 (3.5, 35)
Modified GCPS – disability	Mean (SD)	27.3 (27.6)	30.3 (21.8)
	Median (range)	11.7 (0, 70)	31.7 (0, 73.3)
Modified GCPS – pain	Mean (SD)	28 (24.4)	34 (26.2)
	Median (range)	11.7 (6.7, 73.3)	30 (0, 80)

RDQ = Roland disability questionnaire
Aberdeen = Aberdeen Low Back Pain Scale
GCPS = Graded Chronic Pain Scale
(SD) = standard deviation

Footnote: RDQ questions relate to the day of testing; GCPS relates to the preceding 4 weeks; Aberdeen Low Back Pain Scale to the preceding 2 weeks. RDQ scores are out of 24; Aberdeen Low Back Pain Scale and GCPS are presented out of 100. The higher the score, the greater the disability.

4.5.2 Position awareness in mid-range when moving from slump sitting to extension of the low back

When analysing the data using a t-test, no significant differences were found in the low back position acuity in participants with or without back pain (see Table 4:5).

Table 4:5. Error in low back position awareness in mid-range*

	LBP *n=50*	NLBP *n=50*	mean difference [95% CI]	P value
Error in mid-range	3.08 (1.26)	2.86 (1.34)	-0.22 [-0.74 to 0.30]	0.399

*Data are means (SD)

4.5.3 BMI. Its relationship to reposition error

No correlation was found between BMI and position sense in all participants with LBP (Pearson correlation r value 0.01), or participants without LBP (Pearson correlation r value 0.22).

4.5.4 Pain and disability scores. Their relationship to reposition error

No correlation was found between position sense and pain, and position sense and disability in participants with LBP (Pearson correlation r value range from -0.25 to 0.13).

4.5.5 Years since onset of LBP and the average duration of recurrent episodes. Their relationship to reposition error

No correlation was found between position sense and the number of years since onset of LBP (Pearson correlation r value -0.19), and position sense and the average duration of recurrent episodes in all participants with LBP (Pearson correlation r value -0.21).

4.5.6 Test-retest of position awareness tests

The difference in mean error scores between day 1 and day 2, for people with and without LBP, were small for the position awareness test (Table 4:6). Mean differences for Bland and Altman tests were also small for all participants, between day 1 and day 2, although the difference was smallest for people without LBP. The values for the 95% limits of agreement were smaller and narrower for people without LBP. ICC coefficient values were above 0.50 for people with and without LBP, although higher for test scores on people with no LBP. The results suggest better test-retest reliability of the test in people without LBP.

Table 4:6. Position awareness test-retest mid-range in sitting. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP Reposition error		NLBP Reposition error	
Participant	**Day 1**	**Day2**	**Day 1**	**Day 2**
1	7.14	3.58	1.43	2.75
2	1.29	1.17	2.48	2.28
3	2.40	3.32	4.57	5.00
4	1.51	1.67	2.79	1.98
5	1.97	1.82	2.00	2.81
6	3.14	2.11	2.09	2.12
7	3.20	2.03	0.93	1.59
8	2.63	3.04	1.90	1.57
9	4.85	4.93	2.73	2.14
10	4.61	2.39	3.07	2.85
Bland & Altman				
Mean difference (SD)	-0.67 (1.36)		0.07 (0.67)	
2xSD	2.72		1.33	
95% limits of agreement	-3.39 to 2.05		-1.26 to 1.40	
ICC coefficient	0.59		0.77	
95% CI	-0.02 to 0.88		0.31 to 0.94	

4.6 Discussion

4.6.1 Position awareness in mid-range of low back sagittal movement

In Chapter 3, the largest reposition errors were found in mid-range of spinal movement, when attempting to locate the neutral spinal posture. To investigate this further, this study investigated position awareness in mid-range of low back movement, where muscles play a primary role in position sense. In addition, participants were required to start in a slump sitting position, so that the target positions required greater through-range spinal movement, in comparison to the study in Chapter 3, where participants started in a neutral spinal sitting posture. It was hypothesised that making participants move through a greater range to the “target” positions, would pose a greater challenge to their sensorimotor system and potentially lead to higher degrees of reposition errors. No differences in low back position awareness were found however, when attempting to reproduce mid-range spinal positions between people with and without LBP.

The similarities in low back position awareness, between participants with and without LBP, support the findings of Chapter 3 and others (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000), but are different to other work that has shown position awareness deficits in participants with LBP (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003). Possible reasons for discrepancy between studies are discussed in sections 1.2.6; 3.1; 3.6 and 6.3. They include different interpretation of the relevance of small errors in position sense (Lam et al., 1999; Lee et al., 2010; Lönn, Crenshaw, Djupsjöbacka, Pederson, & Johansson, 2000b; Newcomer et al., 2000; O'Sullivan et al., 2003);small sample sizes (Descarreaux et al., 2005; O'Sullivan et al., 2003); heterogeneous populations (O'Sullivan et al., 2003); poor “control groups” (Gill et al., 1998; Newcomer et al., 2000); methodological variations in assessment procedures (Brumagne et al., 2000; Descarreaux et al., 2005; Gill et al., 1998; Newcomer et al.,

2000); and the number of position awareness tests (Allison et al., 2003).

The small errors in position awareness were possibly due to afferent information from joint or periarticular structures, during testing of "targets" towards the outer range (Grigg, 1994). In order to test for position awareness deficits resulting from trunk muscle dysfunction due to LBP, "target" positions in this study were restricted to mid-range, where joint and periarticular receptors have less influence on positional awareness (Grigg, 1994; Proske et al., 2009). Even though this study deliberately avoided "target" positions in the outer range, the errors in position awareness were small. These small errors remain similar to those found in Chapter 3 and in other studies (Swinkels et al., 2000).

These findings suggest that in the people with LBP in this study, if there was any dysfunction in the segmental muscles and TrA where dense populations of muscle spindles exist (Amonoo-Kuofi, 1983), it did not affect their ability to accurately discriminate spinal position. There is no way of knowing however, whether people with LBP in this study had any dysfunction in these trunk muscles as no measurements of muscle were recorded. To overcome these difficulties ultrasound could be used to investigate for muscle size and EMG to investigate activation and timing of the trunk muscles. The relationship between muscle function and low back position sense, around mid-range of low back sagittal plane movement, could subsequently be investigated in people with and without LBP.

If pain was predominately unilateral, the contra-lateral deep segmental/trunk muscles and those at other spinal levels may have compensated for loss of sensory information about spinal position. This is possible because the extensive neural network in the muscle spindle system allows individual muscle spindles to be influenced by activity in the muscle spindle population in the same muscle or different muscles (Appelberg, Hulliger, Johansson, & Sojka, 1982; Johansson et al., 1991b). Consequently, deficits in position sense in the low back may be difficult to measure. Alterations in low back position acuity are more likely to occur in people who have multi-level, bilateral morphological

and timing changes in muscles with dense populations of muscle spindles e.g. multifidus, TrA (Amonoo-Kuofi, 1983). This would also require the use of ultrasound and EMG analysis in conjunction with testing position sense.

4.6.2 Test-retest reliability of position awareness tests

Data were collected under the same conditions on a different day. As in Chapter 3, the difference in mean error scores in degrees between day 1 and day 2, for people with and without LBP, were small. This may in part be a reflection of the small measurement errors shown in vitro (see section 2:4).

It was found that in people without LBP the mean differences for Bland and Altman tests were smaller and the 95% limits of agreement values were smaller and narrower. In addition, the ICC coefficient value was higher for the test scores on people with no LBP, although the 95% CIs for ICCs were wide for both groups, suggesting uncertainty as to the true reliability of the test (as measured by ICCs).

The results suggest better test-retest reliability of the test in the non-pain participants. This may reflect greater difference in the mean error values and therefore position sense, between day 1 and day 2, for individual participants with LBP. Despite this however, the actual differences in mean error values measured in degrees between day 1 and day 2, also remained very small for people with LBP. As previously mentioned in Chapter 3, all the test-retest results (raw data; Bland and Altman results; ICC values), need to be interpreted together for a better understanding (Rankin et al., 1998).

4.6.3 Limitations of the study

When interpreting the results there are limitations that need to be considered. The disability and pain scores of the participants with LBP were low and unlikely to be representative of people with more severe LBP, whose spinal position awareness may be more adversely affected.

The heterogeneous nature of the LBP in study participants remains an issue, and a reason why these studies have not found significant differences between the the test populations, whereas studies with more homogenous participants with LBP have (O'Sullivan et al., 2003).

At data collection the researcher was not blinded to whether the participant had back pain or not. The recording of the data by the electrogoniometer however, was automated as was the data transfer process into a SPSS database. Subsequently, an independent person coded LBP and NLBP groups, so that the researcher remained “blinded” to participants back pain status during data analysis (see section 4.4.7.2).

4.6.4 Implications of the research

This study was the first large scale study to specifically investigate position sense in mid-range target positions of low back flexion and extension, from a slumped sitting position. Clinical implications are limited, as there was no evidence of sensorimotor changes when testing the ability to locate these mid-range target positions. The results however, suggest positional errors of people with recurrent NSLBP are consistently slightly greater than those of people without LBP. The data from this study can be used in the sample size calculation for future similar studies. Future studies with a more specific, homogenous population of people with LBP, could investigate whether similar tests of position sense result in greater error values in people with LBP in comparison to people without LBP.

4.7 Summary of findings

- No differences were found in the accuracy of low back position awareness in mid-range of low back flexion and extension in sitting between participants with and without LBP.

5 ABILITY TO RETURN TO A "GOOD" SITTING POSTURE AND ITS RELATIONSHIP TO END-RANGE LOW BACK EXTENSION AND FLEXION

5.1 Background

In Chapter 3, participants were aided in initially identifying the neutral sitting position. The results showed similar ability when returning to this position for people with and without LBP, although there was a trend for people with LBP to have slightly greater reposition error. In addition, it was noted participants with LBP often overshot the neutral sitting posture, locating this nearer to their end-range of low back extension. This could have implications for end-range loading of pain-sensitive spinal structures and ongoing LBP, when people attempt to adopt a "good" sitting posture to help manage their LBP.

This current study was designed to investigate people's ability to initially locate and then return to a perceived a "good" sitting posture, rather than a neutral sitting posture identified by the researcher. It was hypothesised that LBP may alter sensorimotor programming, resulting in this patient perceived "good" sitting posture being located closer to end-range extension in people with LBP, whereas people with no LBP, would locate this nearer to a neutral sitting posture.

It has been reported in vitro, that an alteration in low back position of as little as 2 degrees, can substantially alter axial compressive loading stress on the spine (Kiefer et al., 1997). This was a cadaveric study that attempted to find the optimum position around a neutral spinal posture, for compressive load bearing. It found that just 2 degrees of anterior pelvic tilt, enabled the cadaveric thoracolumbar ligamentous spine, to carry axial compressive loads as high as 400 N (Kiefer et al., 1997).

The importance of a neutral sitting posture in preventing or managing LBP cannot be underestimated. A neutral lumbar posture is considered the position least likely to cause low back pain and the ability to accurately discriminate this position, may be particularly important in the prevention and management of LBP (Saal & Saal, 1989).

Accurate sensory feedback from, and activation of, appropriate trunk muscles are essential for the appreciation and maintenance of good spinal posture (Cholewicki et al., 1997; Holm et al., 2002). Poor low back posture however, can occur in people with and without LBP (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008; Tüzün, Yorulmaz, Cindas, & Vatan, 1999). If however, trunk muscles are dysfunctional due to low back pain (Hides et al., 1996; Hodges et al., 1996), work-related activity and/or fatigue (Hurley et al., 2000), then a decrease in muscle spindle sensitivity might impair people's ability to locate a good spinal posture. Consequently, any resultant poor sitting posture, such as the spine braced into extension, will stress innervated tissues, thereby causing abnormal excessive loading, leading to pain or aggravation of LBP (Bovenzi et al., 1992; Keyserling, 2000; Kumar, 1990) and possible joint damage (Panjabi, 2006; Reeves et al., 2009). It is important therefore, for studies to investigate low back sitting posture in people with and without LBP.

As low levels of muscular activity are required to maintain the neutral lumbar spinal position, the spine appears to be vulnerable to buckling i.e. giving way (Cholewicki et al., 1996). To minimise LBP in sitting, people may stiffen their spine into extension, using the superficial back muscles because of weakness in the primary stabilising deep trunk muscles (O'Sullivan, 2000). This could be a conscious and / or unconscious reaction. People with LBP may use this as a strategy to protect their low back from pain, yet over-activity of the back extensor muscles is likely to increase shear forces and compressive loading (van Dieën & de Looze, 1999) of pain-sensitive structures in the posterior part of the spine, such as the facet joints, nervous tissue and posterolateral disc. When stressing innervated spinal tissues there is a

decrease in protective muscle activation of multifidus (Solomonow et al., 1999), which predisposes the spine to injury and pain, or maintenance of chronic pain (O'Sullivan et al., 2006). Therefore maintenance of poor posture in prolonged sitting may cause or aggravate LBP (Bovenzi et al., 1992; Keyserling, 2000; Kumar, 1990; Pope et al., 2002). To minimise repetitive poor posture and prolonged habitual joint loading, accurate body position awareness is important (Shirazi-Adl et al., 2002).

Aim:

The aim of this study was to investigate the accuracy in repositioning to a “good” sitting posture in people with and without recurrent non-specific low back pain and estimate where they considered was a “good” sitting posture in relation to end-range low back extension.

A secondary aim was to investigate any difference in range of forward and backward movement of the low back, in people with and without recurrent non-specific low back pain. In addition, a secondary aim was to investigate the position of participants “good” sitting posture in relation to end-range low back flexion.

The study also investigated the test-retest reliability of data for the position awareness test, the relationship of “good” sitting posture to end-range and the range of forward and backward movement of the low back.

5.2 Null hypothesis

5.2.1 Primary null hypothesis

1. There is no difference in the ability to accurately reposition to a “good” sitting posture between people with recurrent non-specific low back pain and people who have never reported low back pain.
2. There is no difference in the position of “good” sitting posture in relation to end-range low back extension between people with recurrent non-specific low back pain and people who have never reported low back pain.

5.2.2 Secondary null hypothesis

1. There is no difference in total range of low back extension and flexion in sitting between people with recurrent non-specific low back pain and people who have never reported low back pain.
2. There is no difference in the position of “good” sitting posture in relation to end-range low back flexion between people with recurrent non-specific low back pain and people who have never reported low back pain.

5.3 Methodology

A quantitative approach was used to compare position awareness between people with and without LBP, with reposition error the quantitative value for comparison (Gill et al., 1998; Newcomer et al., 2000; O'Sullivan et al., 2003) measured in degrees using a flexible M180B electrogoniometer (Biometrics Ltd, Gwent, UK) (Figure 2:1).

5.4 Methods

Participants were the same as those in Chapter 4, therefore, the design; ethical approval and research governance; participant profiles and entry criteria; exclusion criteria; sample size; recruitment; data collection procedure for clinical examination and self-administered questionnaires; position awareness in the low back for calibration of electrogoniometer prior to test of position sense and data analysis, were as described in Chapter 4 (sections 4.4.1 to 4.4.7). For the primary hypothesis, the level of significance was set at $P < 0.05$. To minimise the possibility of finding a significant result by chance due to multiple testing, the level of significance was set at $P < 0.01$ for the secondary hypothesis.

5.5 Additional methods specific to this study

5.5.1 Reposition to perceived good sitting posture

An electrogoniometer (Biometrics Ltd, Gwent, UK) was placed by the researcher over the lumbosacral spinous processes L1 and S1 of each participant in sitting, and kept in situ using double-sided sticky tape (Hurley et al., 2000). Participants were seated with their hips and knees at approximately 90 degrees flexion and their feet just off the ground. Participants were told the test movements should not cause LBP. If this occurred, they were to stop, and report it to the investigator.

Starting from a slumped sitting position (Figure 4.1), participants were asked to extend their low back slowly and stop at what they considered to be a good sitting posture - the “target” position. No other definition or instruction was given to participants on how to locate this good sitting posture. It was purposely left for each participant to decide on what they considered was a good sitting posture. They were asked to concentrate on, and remember this “target” position for 3-seconds (Maffey-Ward et al., 1996), before returning to the slumped starting position. After 3-seconds, each participant was asked to return to the “target” position; the position they return to - the “reproduced” position - was recorded. They then returned to the slump position. They were asked to return to this “target” position 10 times, as recommended and similar to the number found in other studies (Allison et al., 2003; Hurley et al., 1996; Hurley et al., 1998a).

To prevent visual feedback, participants kept their eyes closed during the location of each “target” position and when reproducing this position. They were allowed to open their eyes between the 10 tests, to enable them to “reset” their perceptual field to minimise attention drift.

The absolute error between each “target” and “reproduced” position was calculated in degrees. The reposition error was calculated as a mean of the 10 absolute error values and used in the analysis.

5.5.2 Range of low back sagittal plane movement

To record the total range of low back movement participants were asked to slump and then straighten their low back through their full range of movement. If pain was to limit their range, they were instructed to stop and report it to the investigator. This was repeated four times – two of these ranges of movement tests were done immediately before and two immediately after the reposition tests, so as to take account of any possible changes in range, following the

reposition tests. As these tests of range were in addition to the reposition tests, four repetitions were chosen to minimise the potential of aggravating LBP by performing too many through range movements. Pain provocation would have had ethical implications and could have affected the ability of participants to complete the reposition tests.

5.5.3 Test-retest of position awareness tests for reposition to perceived good sitting posture and range of low back sagittal movement

Test-retest data were recorded for ten people with and ten people without LBP. Data were collected under the same conditions on a different day.

5.6 Results

Participant characteristics data have been presented in section 4.5.1 and 4.5.1.1.

5.6.1 Low back position awareness when returning to a "good" sitting posture

No significant differences were found in position awareness, when returning to a "good" sitting posture, between participants with and without LBP (see Table 5:1).

Table 5:1. Error in low back position awareness in all participants when returning to their "good" sitting posture*

	LBP *n=50*	NLBP *n=50*	mean difference [95% CI]	P value
Good posture	3.95 (2.84)	3.48 (2.51)	-0.47 [-1.53 to 0.59]	0.382

*Data are mean degrees (SD)
95% CI = 95 percent confidence interval

5.6.2 Position of "good" sitting posture in relation to end-range

Participants with low back pain had a significantly smaller range of movement between their "good" sitting posture and their end of range of low back extension, than participants without LBP (12.47 SD8.46, v's 16.51 SD9.41 degrees respectively; P=0.026; Table 5:2). There was a non-significant difference in the range of movement from "good" sitting posture to the end-range low back flexion between participants with and without LBP (Table 5:2).

Table 5:2. Position of "good" sitting posture in relationship to end-range of low back extension and flexion*

	LBP *n=50*	NLBP *n=50*	mean difference [95% CI]	P value
Good posture to EOR extension	12.47 (8.46)	16.51 (9.41)	4.04 [0.48 to 7.59]	0.026
Good posture to EOR flexion	23.15 (10.05)	27.41 (11.55)	4.26 [-0.04 to 8.56]	0.052

*Data are mean degrees (SD)
95% CI = 95 percent confidence interval
EOR = end of range

5.6.3 Total range of low back flexion and extension during sitting

Participants with LBP had significantly less total range of flexion and extension movement in the low back, than participants without LBP (35.39 SD10.93, v's 43.18 SD13.57 degrees respectively; P=0.002; Table 5:3).

Table 5:3. Total range of low back flexion and extension in sitting*

	LBP *n=50*	NLBP *n=50*	mean difference [95% CI]	P value
ROM	35.39 (10.93)	43.18 (13.57)	7.79 [2.90 to 12.68]	0.002

*Data are mean degrees (SD)
95% CI = 95 percent confidence interval

5.6.1 Relationship with BMI

No correlation was found between BMI and returning to a "good" sitting posture, BMI and the position of "good" sitting posture in relationship to end-range of low back extension and flexion, and BMI and total range of flexion and extension in participants with LBP (Pearson correlation r value range from 0.03 to 0.09) or in participants without LBP (Pearson correlation r value range from -0.04 to 0.11).

5.6.2 Relationship with pain and disability scores

No correlation was found between returning to a "good" sitting posture or the position of "good" sitting posture in relationship to end-range of low back extension and flexion, with either pain or disability scores (Pearson correlation r value range from -0.28 to 0.19).

No correlation was found between total range of flexion and extension, and pain and disability scores in participants with LBP (Pearson correlation r value range from -0.29 to 0.08).

5.6.3 Relationship with the years since onset of recurrent LBP and the average duration of recurrent episodes.

No correlation was found between the number of years since onset of LBP with returning to a “good” sitting posture; with the position of “good” sitting posture in relationship to end-range of low back extension and flexion; and with the total range of flexion and extension (Pearson correlation r value range from -0.19 to 0.02).

No correlation was found between the average duration of recurrent episodes with returning to a “good” sitting posture; with the position of “good” sitting posture in relationship to end-range of low back extension and flexion; and with the total range of flexion and extension (Pearson correlation r value range from -0.19 to 0.02).

5.6.4 Test-retest of position awareness tests

For test-retest of returning to a “good” sitting posture; of “good” sitting posture in relationship to end-range of low back extension and flexion; and range of low back flexion and extension, the difference in mean error scores in degrees between day 1 and day 2, were smaller for people without LBP (Table 5:4 to 5:7). For Bland and Altman tests, the mean differences between day 1 and day 2, were smaller and the 95% limits of agreement were smaller and narrower for people without LBP. ICC coefficient values were much higher for the tests on people without LBP. The results suggest better test-retest reliability of the tests in people without LBP.

Table 5:4. Test-retest returning to "good" sitting. Mean reposition error in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP		NLBP	
	Reposition error		Reposition error	
Participant	Day 1	Day2	Day 1	Day 2
1	15.12	1.75	0.94	1.75
2	2.12	0.79	3.23	5.01
3	4.38	1.62	4.50	4.69
4	1.44	6.76	1.21	1.21
5	4.21	2.00	4.07	2.02
6	2.93	1.55	1.74	2.36
7	5.07	2.16	0.71	0.66
8	0.90	4.01	1.38	5.84
9	2.16	2.25	1.04	2.13
10	6.67	3.50	6.05	7.20
Bland & Altman				
Mean difference (SD)	-1.86 (4.91)		0.80 (1.65)	
2xSD	9.82		3.30	
95% limits of agreement	-11.68 to 7.96		-2.50 to 4.10	
ICC coefficient	-0.20		0.67	
95% CI	-0.72 to 0.46		0.12 to 0.91	

Table 5:5. Test-retest of "good" sitting posture in relationship to end-range of low back extension. Range in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP		NLBP	
	Range to end of extension		Range to end of extension	
Participant	Day 1	Day2	Day 1	Day 2
1	11.11	10.98	8.01	3.20
2	10.22	0.13	17.42	17.91
3	2.25	1.48	16.88	11.97
4	8.60	0.50	10.71	5.31
5	15.39	8.86	22.19	16.43
6	15.08	12.33	4.32	0.07
7	4.05	1.76	2.34	0.50
8	5.45	17.42	22.95	22.95
9	5.81	3.06	5.54	5.54
10	17.42	4.54	2.20	13.07
Bland & Altman				
Mean difference (SD)	-3.43 (6.85)		-1.56 (5.00)	
2xSD	13.70		10.00	
95% limits of agreement	-17.13 to 10.27		-11.56 to 8.44	
ICC coefficient	0.25		0.80	
95% CI	-0.42 to 0.74		0.39 to 0.95	

Table 5:6. Test-retest of "good" sitting posture in relationship to end-range of low back flexion. Range in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP		NLBP	
	Range to end of flexion		Range to end of flexion	
Participant	Day 1	Day2	Day 1	Day 2
1	28.26	34.92	16.07	20.97
2	14.94	16.92	22.46	11.57
3	24.08	38.03	40.37	43.83
4	16.70	21.78	20.88	23.49
5	18.27	27.40	23.44	24.53
6	15.44	28.13	16.15	18.95
7	31.64	24.93	20.84	23.36
8	25.43	16.79	26.55	39.60
9	29.47	35.69	25.92	24.57
10	16.51	23.00	28.89	30.47
Bland & Altman				
Mean difference (SD)	4.69 (7.41)		1.98 (5.89)	
2xSD	14.82		11.78	
95% limits of agreement	-10.13 to 19.50		-9.80 to 13.76	
ICC coefficient	0.44		0.76	
95% CI	-0.22 to 0.82		0.28 to 0.93	

Table 5:7. Test-retest of range of low back flexion & extension. Mean range in degrees on day 1 and day 2; Bland and Altman tests; ICCs

	LBP		NLBP	
	Range of flexion extension		Range of flexion extension	
Participant	Day 1	Day2	Day 1	Day 2
1	39.38	45.90	24.08	25.24
2	25.16	16.99	39.87	28.33
3	26.33	37.62	57.24	58.43
4	25.29	22.20	31.59	29.23
5	33.66	36.45	45.63	38.50
6	30.51	41.40	18.88	19.83
7	35.69	24.95	22.75	23.40
8	30.38	33.71	49.79	61.02
9	25.45	35.91	27.83	31.55
10	35.62	31.52	36.97	43.23
Bland & Altman				
Mean difference (SD)	1.92 (8.09)		0.41 (6.42)	
2xSD	16.17		12.84	
95% limits of agreement	-14.25 to 18.09		-12.43 to 13.26	
ICC coefficient	0.39		0.89	
95% CI	-0.28 to 0.80		0.61 to 0.97	

5.7 Discussion

5.7.1 Low back position awareness when returning to a “good” sitting posture

This study found no differences between people with and without LBP, in the accuracy of low back position awareness when attempting to reproduce a “good” sitting posture. These findings are similar to previous chapters and other studies that found no differences in low back position awareness, between participants with and without LBP (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000). The findings are however, different to other studies that have identified greater position awareness deficits in participants with LBP (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003).

Possible reasons for discrepancy between studies are discussed in sections 1.2.6; 3.1; 3.6 and 6.3. They include small sample sizes (Descarreaux et al., 2005; O'Sullivan et al., 2003); heterogeneous populations (O'Sullivan et al., 2003); poor “control groups” (Gill et al., 1998; Newcomer et al., 2000); methodological variations in assessment procedures (Brumagne et al., 2000; Descarreaux et al., 2005; Gill et al., 1998; Newcomer et al., 2000); the number of position awareness tests (Allison et al., 2003); and different interpretation of the relevance of small errors in position sense (Lam et al., 1999; Lee et al., 2010; Lönn et al., 2000b; Newcomer et al., 2000; O'Sullivan et al., 2003).

Although people with and without LBP could accurately reproduce their perceived “good” sitting posture, the location of this position was different between pain and non-pain participants. In a study of 17 people with no history of LBP (mean age=21 years), it was reported that they positioned their “ideal” neutral low back sitting posture, defined as a slight lumbar lordosis and relaxed thorax, similarly to a tester perceived neutral sitting posture (O'Sullivan et al., 2010). The

measurement of posture was between L4 to S1, so excluded other segmental levels in the low back however, it does suggest people without LBP can reliably find a neutral sitting posture.

More recently, it was reported that 90 participants with non specific chronic LBP had significantly greater error when repositioning to a therapists identified neutral sitting posture, when compared to 35 people without LBP; 7.7 degrees (SD 4.1) versus 1.8 degrees (SD 0.8), respectively. Comparisons of actual error values with other studies are difficult, as in this study they are the sum of 4 angles between L1 and L5. In addition, the pain participants were classified into sub-groups (O'Sullivan, 2005) and those with an active extension pattern repositioned their low back into a more extended posture and those with an active flexion pattern repositioned into a more flexed posture (Sheeran, Sparkes, Caterson, Busse-Morris, & van Deursen, 2012). This remains an area that requires further investigations, to see if consistent differences occur between people with and without LBP.

The study in Chapter 3 suggests that if people are given instruction regarding a neutral spinal posture, they perform similarly in identifying this posture regardless of a history of recurrent LBP or no history of LBP. If however, they are asked to locate a perceived “good” sitting posture, even though people with and without LBP may both accurately reproduce this position, the results in this chapter suggest this position may be located differently between the two groups.

5.7.2 Position of “good” sitting posture in relation to end-range

In this chapter, the participants with LBP positioned their “good” sitting posture significantly closer to their end-range extension, than people without LBP. In addition to the statistical significant difference between people with and without LBP (P = 0.026), the raw data showed that people with LBP positioned their “good” sitting posture 4.04 [CI = 0.48 to 7.59] degrees closer to end-range extension than people without

LBP. This difference could have implications for compressive loading (Kiefer et al., 1997; Shirazi-Adl et al., 2002) and end-range loading of pain-sensitive structures (Panjabi, 2006), and will require further biomechanical modelling / testing.

It was noted during testing that people with LBP commonly “fixed” their back into extension, with excessive anterior tilt of the pelvis, and a visible bracing effect from overactive back extensor muscles. On reflection it would have been useful to have used EMG in an attempt to quantify this activity, so as to possibly identify any differences between people with and without LBP. This visible over-activity of the back extensor muscles was possibly facilitated by the central nervous system (CNS) in response to pain or anticipation of pain. This could have a splinting effect on the trunk and may in part be: (1) an attempt to stiffen the trunk; (2) the result of increased muscle activity, required to limit flexion range; or (3) a belief in patients that an extended low back posture is recommended in managing LBP, a belief perhaps reinforced by therapists advocating excessively upright, extended postures in sitting.

Over-activity of the back extensor muscles however, will slow down and restrict movement (especially into flexion). Increased muscle activity in more lordotic sitting postures, particularly in multifidus (Claus, Hides, Moseley, & Hodges, 2009), could cause excessive increase in the compressive loading on the spine, especially if coactivating with the abdominals (van Dieën et al., 1999), which is likely to occur when bracing (Grenier et al., 2007).

In addition, biomechanical modelling has shown that muscle forces significantly increase from 1N/m at a neutral lordotic posture (neutral was located 16 to 20 degrees from an excessive lordosis), to 50N/m at an excessive lumbar lordosis (Shirazi-Adl et al., 2002). This in vitro position of a neutral spinal posture is similar to the distance of 16.51 degrees from their perceived “good” sitting posture to end-range extension found in people without LBP in this chapter. This is in contrast to the distance of 12.47 degrees found in people with LBP. They therefore sit closer to an excessive lumbar lordosis when

attempting to find their “good” sitting posture, in comparison to people without LBP.

Similarly, there are significant increases in facet joint forces and shear forces on discs with an excessive lumbar lordosis (Shirazi-Adl et al., 2002). Furthermore, if a muscle has to sustain over-activity for long periods of time, it is likely to cause local or referred muscle pain. These mechanisms may be aetiologic in the recurrence and maintenance of LBP that is seen in many patients (Johansson et al., 1991b; Pedersen et al., 1997) (see section 1.2.2.3). Avoiding a sustained rigid upright sitting posture, as well as avoiding a passive slumped posture, may help reduce pain in some people who experience LBP during sitting (O'Sullivan et al., 2010).

This splinting effect into extension could be explained: the motor output in response to pain or in anticipation of pain, is believed to encourage escape, to minimise aggravation of painful tissue (Moseley, 2003). Therefore, as low back flexion commonly aggravates pain-sensitive tissue, the natural escape would be to extend the spine, to limit provocation, with increased activity of the more superficial trunk muscles commonly seen in people with LBP (Hodges et al., 2003). This motor output is consistent with a splinting effect and is believed to be primarily, a higher centre response (Moseley, 2003), suggesting this is not just an unconscious spinal reflex response, but at least in part a reaction under conscious control.

A recent study asked 295 physiotherapists to identify what they considered to be the best sitting posture. Therapists were given nine postures to choose from and 54.9% selected what was considered a more neutral spinal posture that was not close to an individual’s end-range, but 30.5% selected a more upright extended posture that was reported to be the most extended posture for the thoraco-lumbar spine and the second most extended posture for the lumbar spine (O'Sullivan, O'Sullivan, O'Sullivan, & Dankaerts, 2012). It is suggested that the beliefs of therapists influence the management of their patients (Darlow et al., 2012) and thus may result in a significant proportion of patients with LBP been taught a more upright lumbar sitting posture

(O'Sullivan et al., 2012). The authors suggested that studies were needed that investigated what people with LBP thought was a good sitting posture, as investigated in chapter 5.

It would be interesting to repeat this test of position of good sitting posture, after a period of prolonged slump, a posture commonly adopted when sitting (Dolan et al., 2006).

5.7.3 Total range of low back flexion and extension during sitting

In muscle pain, decreased activity of the agonist and increased activity of the antagonist muscles can occur (Graven-Nielsen, Svensson, & Arendt-Nielsen, 1997; Lund et al., 1991). In addition, pain induced in erector spinae reduces speed and range of movement into flexion, associated with a loss of the flexion-relaxation response (Zedka et al., 1999). In this pain-adaptation model of muscle activation in response to pain (Lund et al., 1991), this increased activity of the antagonist is believed to refer to muscles that are lengthening (van Dieën et al., 2003b) e.g. the superficial back extensors when sitting slumped. In the low back, this would support the theory that changes in muscle activation are aimed at avoiding movement stresses on pain-sensitive and possibly injured, spinal structures. The structures protected include the richly innervated posterolateral portion of the intervertebral disc, sensitive nerve tissue and other pain-sensitive structures.

Limited range of low back movement in participants with LBP, in particular flexion, is therefore consistent with the CNS attempting to protect the spine from flexion loading. Facilitation of the back extensor muscles, to limit flexion range, may be a common feature in people with LBP.

The increase in lumbar erector spinae muscle activation that is found in people with low back pain during low back flexion, could therefore explain a loss flexion range. In people without LBP, the sudden onset of electrical silence in the activity of the back extensor muscles at a

point towards end of lumbar flexion (i.e. the flexion-relaxation phenomenon), and the range of sagittal movement in the low back are related (Neblett et al., 2003). The absence of this flexion-relaxation phenomenon in people with LBP, has been observed in both standing (Watson, Booker, Main, & Chen, 1997b) and sitting (Dankaerts, O'Sullivan, Burnett, & Straker, 2006; Mak et al., 2010). This results in a loss of range of sagittal movement in people with LBP (Triano & Schultz, 1987). This is likely to be a protective mechanism to decrease segmental range of motion (segmental sagittal rotation) (Kaigle, Wessberg, & Hansson, 1998), protecting pain-sensitive structures from excessive lengthening. Interestingly, evidence suggests flexion-relaxation in sitting can be normalised following rehabilitation and simultaneous improvements occur in range of low back movement (Mak et al., 2010).

The people with LBP in this study had an episode of LBP within the previous 3 months, lasting greater than 24 hours. Any protective loss of range due to this painful episode may still have remained at the time of testing. Limiting spinal range may be beneficial in the short-term, to limit stresses and loading of pain-sensitive structures; however it is important to remember that reduced spinal flexibility affects normal function and nutrition to joints, and can itself result in pain.

This observation of a possible loss of flexion range is supported by a small scale study of back pain patients in the absence of nerve root signs, where decreased lumbar flexion and normal range of extension was found using biplanar X-rays (Pearcy, Portek, & Shepherd, 1985).

In a much larger study of 138 people with LBP, the measurements recorded using a spinal motion analyser, showed decreases in the range of flexion and extension, when compared to the results of people without LBP from a previous study (McGregor, McCarthy, Doré, & Hughes, 1997; McGregor, McCarthy, & Hughes, 1995). The measurements recorded for people with and without LBP showed great variability, with the most noticeable differences in range compared to healthy individuals, occurring in patients with spinal stenosis, disc prolapse or degenerative disc disease (McGregor et al., 1997). As the

range of flexion and extension may be variable, depending on the diagnosis of LBP, future studies may need to consider underlying pathology. The relationship of pain to pathological changes and current symptoms is however, far from consistent, and so comparisons between people with and without LBP may prove difficult.

There are other difficulties associated with measuring and comparing the range of lumbar movement from different studies, due in part to the variety of instruments and methodologies used. It has been investigated in LBP using in vivo clinical measurements (Loebl, 1967; Macrae & Wright, 1969; McGregor et al., 1995; Taylor et al., 1980), radiographs (Allbrook, 1957; Troup, Hodd, & Chapman, 1967) and in cadavers (Hilton, Ball, & Benn, 1979; Taylor et al., 1980).

Clinical measures such as the spondylometer (Taylor et al., 1980), inclinometer (Loebl, 1967) or spinal motion analyser (McGregor et al., 1995), provide non-invasive, relatively quick and easy clinical information about lumbar motion, but not segmental movement. Their accuracy depends on the instrument used and ability of the operator to identify bony landmarks by palpation. These tools commonly only measure movement in the sagittal plane, although the spinal motion analyser will measure movement in three planes.

Biplanar radiographs, taken by two X-ray tubes at right angles to each other, record sagittal movements more accurately, than lateral radiographs alone. They detect simultaneous movements using an anterior-posterior and lateral radiograph, allowing 3-directional movements to be calculated (Pearcy et al., 1984). Radiography however, involves radiation exposure, and is expensive in terms of equipment and time.

Although cadaveric studies allow very precise measurements with correlation to pathological changes, the post-mortem changes, lack of CNS involvement and common practice of removing muscles makes comparison to the living difficult (Bogduk, 1997).

It was decided that the study in this chapter would measure the range of low back movement, in conjunction with collecting data on position

awareness using an electrogoniometer. The accuracy of this simple-to-use instrument is reported in Chapter 2. It is acknowledged that these measures of active range of low back movement are not a true representation of range, as the forward or backward displacement that occurs during sagittal movement, is not recorded by the electrogoniometer.

Recording in the sagittal plane only, is similar to measurements taken in a large scale study of 960 participants using a spondylometer (Twomey et al., 2000). This is perhaps the most appropriate instrument to compare the findings of total sagittal range from the study in this chapter, rather than a comparison with measurements using biplanar X-rays (Pearcy et al., 1984), inclinometer (Loebl, 1967) or spinal motion analyser (McGregor et al., 1995). The spondylometer measurements, similarly recorded movement between L1 and the sacrum, however a general population was measured with no differentiation reported between people with and without LBP (Twomey et al., 2000). The authors reported their finding for mean total range for all participants to be 40 degrees, compared to 39.42 degrees in participants of similar age in the study in this chapter. A cadaveric study by the same authors, using the spondylometer on 204 fresh specimens within 24-48 hours of death, found the sagittal range to be a mean of 44.63 degrees, when comparing similar age ranges (Taylor et al., 1980; Twomey, 1979).

Comparing study findings on spinal range of movement is also difficult because of differences in the start position i.e. standing or sitting. For the study in this thesis, the range was recorded in sitting, whereas others recorded in standing (Allbrook, 1957; Macrae et al., 1969; Pearcy et al., 1984), and prone lying and sitting (Troup et al., 1967). In addition, there are gender, age and race differences to consider. In a study of 11 males with no pain (mean age 29.5 years), recordings using biplanar X-rays, suggest the total range of flexion and extension from L1 to S1 ranges, is 68 degrees (Pearcy et al., 1984). In white females aged 20-60 years, total range from T12 to S1 was approximately 74 degrees when recorded using an electronic

inclinometer (Trudelle-Jackson et al., 2010). The mean ages (29.5 years) of participants in the study by Pearcy et al., (1984), were much lower than the study in this chapter (mean age 46.5 years LBP; 43.6 NLBP) and this may account for some of the differences seen, as range of back movement is known to decrease with age (Loebl, 1967; Macrae et al., 1969; Taylor et al., 1980; Troke, Moore, Maillardet, Hough, & Cheek, 2001).

In addition, consideration should also be given to the spinal levels measured as T10 (Hilton et al., 1979); T12 (Trudelle-Jackson et al., 2010); T12/L1 (McGregor et al., 1995) or L1 (Pearcy et al., 1984; Taylor et al., 1980) to sacrum have been investigated. As each lumbar level has approximately 14 degrees total range of flexion and extension (Pearcy et al., 1984), studies including measurement of T12/L1 will show greater total low back movement, than those recording L1 to sacrum, as in the study in this chapter. Further studies, similar to Pearcy et al., (1984), are needed to be certain of the contribution of T12/L1 spinal segment to the total range of flexion/extension in the low back. This would allow more accurate comparison between studies.

5.7.4 Test-retest reliability of position awareness tests, the relationship to end-range and range of flexion-extension

When returning to a “good” sitting posture, the difference in mean error scores in degrees between day 1 and day 2, were smaller for people without LBP. Smaller differences in degrees in people without LBP were also found in all other tests including “good” sitting posture in relationship to end-range of low back extension and flexion and for range of low back flexion and extension. The findings of the raw data and the results for Bland and Altman tests and the ICC coefficient value, suggests better test-retest reliability of the tests in people without LBP. The 95% CIs for ICCs were however wide for both groups, suggesting uncertainty as to the true reliability of the tests (as measured by ICCs).

The poorer results for test-retest reliability of the tests in people with LBP may be due to greater difference in the mean error values and therefore position sense, between day 1 and day 2, for individual participants with LBP. Interestingly, other than for range of movement test-retest data, the differences in test scores measured in degrees between day 1 and day 2, also remained very small for people without LBP. This reinforces the importance of interpreting the raw data, Bland and Altman results and ICC values for a better understanding of test-retest reliability (Rankin et al., 1998).

5.7.5 Limitations of the study

This study has similar limitations to Chapter 4. The low scores for disability and pain indicate that participants were not severely affected. In people with more severe LBP, their sensorimotor system, including spinal position awareness and the relationship of their perceived "good" sitting posture to end-range extension, may have been more adversely affected.

The finding that participants with LBP position their "good" sitting posture closer to end-range extension, may just be a consequence of an overall decrease in their range of low back extension in comparison to people without LBP. To be certain, a study would need to accurately locate and compare the position of end-range extension and flexion, in people with and without LBP. On observation however, participants with LBP did not appear to have a visible loss of lumbar extension, rather a visible loss of flexion consistent with the protective response previously described (section 5.7.2). Furthermore, they commonly splinted their back into extension, with a visible bracing effect from overactive back extensor muscles.

Additionally, there needs to be an understanding of where extension and flexion start in order to be able to attribute the decrease in the total sagittal range found in this study in people with LBP, to a decrease in predominately flexion or extension, or both. Although in

this study it was noted during testing, that people with LBP appeared to loose flexion rather than extension range, without confirmation of where extension or flexion starts, this remains unsubstantiated.

Other studies have recorded flexion and extension from a participant's initial resting posture. Clinical observations suggest this would result in a highly variable starting position, and therefore, very different ranges of flexion and extension seen across individuals with or without LBP. In people without LBP for example, their habitual sitting posture was significantly closer to end-range flexion than the location of their "ideal" sitting posture (O'Sullivan et al., 2010).

These findings (O'Sullivan et al., 2010) and those of the current study suggest that the start point of flexion and extension in sitting, could be dependent on the terminology used and the interpretation when asking people to locate a particular sitting position i.e. initial resting posture; their habitual sitting posture; "ideal" sitting posture; their perceived "good" sitting posture. Others comment that variation in the amount of lumbar lordosis will lead to an artificial increase or decrease in the recorded range of flexion and extension (Sullivan, Dickinson, & Troup, 1994). As a consequence of the confusion of where flexion and extension starts, in the study in this chapter, the total range of sagittal movement was recorded and no attempt was made to quantify the individual ranges of flexion or extension. The relationship of people's "good" sitting posture to their end-range extension was the priority in this study.

From childhood to adolescence, low back mobility has been shown to decrease considerably (Twomey et al., 2000) and, from adulthood, there is a more gradual decline (Loebl, 1967; Taylor et al., 1980), with increased disc stiffness, due to dehydration and fibrosis of older discs being the primary cause (Twomey & Taylor, 1983).

In the current study, there was no consideration made for age ranges, gender or ethnicity when comparing the total range of movement. The mean age, number of males to females and ethnicity however, were similar across the groups. A similar large scale study could be designed,

to consider age and gender matching, although in the normal population, it appears there is variability in the total range at all ages (Hilton et al., 1979; McGregor et al., 1995) and in both genders (Macrae et al., 1969; McGregor et al., 1995). The evidence for gender differences however, is not consistent (Hilton et al., 1979; Loebl, 1967), with a suggestion that with increasing age any gender differences in range diminish (Taylor et al., 1980).

A consideration when designing future studies, is that measurement of low back range should be recorded in the afternoon or evening, when at its greatest after people have been upright for sometime (Dvorák et al., 1995). This is not believed to have been a major concern in the study in this chapter, as most recordings were taken after midday and there was a similar amount of people with and without LBP measured in the morning, with all these measured after 10.30am. Different spinal structures are reported to be more heavily loaded at different times of the day, which in turn could result in diurnal variations in low back symptoms (Adams, Dolan, Hutton, & Porter, 1990). It may therefore be important to test any spinal measures at comparable times throughout the day, to minimise the possibility of diurnal variations in the outcome of any spinal measurements taken.

Finally, consideration should also be given to the role and proportion of movement and muscle activity occurring at the upper trunk, hips and knees. Movement is a co-ordinated activity involving multiple joints and muscles and it is perhaps arbitrary to just look at the low back in isolation. Investigating for example, the role of the gluteal muscles, their interaction with activity of muscles of the trunk and how this relates to low back position sense, would be an important addition of knowledge.

5.7.6 Implications of the research

As far as could be determined, this study was the first large scale study to investigate where people believe their “good” sitting posture should be located. The ability to reposition to this posture is similar for people

with recurrent NSLBP and without LBP, and clinical implications are therefore limited. The error values for people with LBP are slightly greater than those for people without LBP. This is similar for the test-retest data when returning to this "good" sitting posture. Further studies are needed to see if people with more severe LBP have larger error values than found in the people with LBP in this study.

Measuring "usual" posture and awareness of "good" posture in relation to the end-range may prove to be a more useful measure, than comparing either postural awareness or range of motion alone. These end-range postures are towards the elastic zone of motion and are where there is increase stress on passive structures (Scannell & McGill, 2003), and could have an important relationship with LBP (Panjabi, 2006). In order to investigate this fully, studies will need to accurately record the end-range flexion and extension positions. To be able to do this, studies at the very least, should consider a participant's initial resting posture (Coates, McGregor, Beith, & Hughes, 2001). Ideally they should have certainty as to the true range of flexion and extension, with reference to a recognised, repeatable and measureable start point.

The data from this study can be used in the sample size calculation for future similar studies.

5.8 Summary of findings

- No differences were found in the accuracy of low back position awareness when returning to their "good" sitting posture between participants with and without LBP.
- People with LBP positioned their "good" sitting posture significantly closer to end-range of low back extension than participants without LBP.
- People with LBP had significantly less total range of low back sagittal plane movement than participants without LBP. There is theoretical evidence to suggest this was primarily due to a loss of lumbar flexion.

6 GENERAL DISCUSSION

6.1 Summary of findings

The studies in this thesis found;

- The electrogoniometer is a valid and reliable measure of angles between -60 to 0 to +60 degrees of movement, when compared to the measurements of a very accurately calibrated, bevel protractor (Chapter 2).
- No differences in the accuracy of low back position awareness between people with recurrent NSLBP and without LBP, in sitting or standing, either before or after-work (Chapter 3).
- Reposition errors were greatest when people (with recurrent NSLBP and without LBP) were returning to a neutral sitting posture (Chapter 3).
- Larger reposition errors were evident in people with recurrent NSLBP when returning to the neutral sitting posture when compared to people without LBP before-work, although these differences were small and non-significant (Chapter 3).
- Sedentary occupation had no effect on low back position acuity either before or after-work. Unfortunately, uncertainty exists about the effect of occupation on position sense in manual workers and drivers, as the sample sizes in these occupations were too small (Chapter 3).
- There were no differences in the accuracy of low back position awareness in mid-range of low back sagittal plane movement in sitting or when returning to a “good” sitting posture between people with recurrent NSLBP and without LBP (Chapters 4 and 5).
- People with recurrent NSLBP positioned their “good” sitting posture significantly closer to end-range of low back extension than people without LBP (Chapter 5).
- People with recurrent NSLBP had significantly less total range of low back sagittal plane movement than people without LBP (Chapter 5).

These studies found no differences in the accuracy of low back position awareness between participants with and without LBP (Chapters 3 to 5).

The accuracy to reproduce random target positions during forward bending and backward bending (flexion and extension) of the low back in sitting and standing, was no different in people with recurrent NSLBP and people without LBP, before or after a shift of work (Chapter 3). A person's occupation had no effect on low back position acuity, although the sample size in the different occupational groups was too small to enable drawing strong inferences - only the sedentary group achieved the sample size required for power. The largest reposition errors were evident in people when returning to a neutral sitting posture from the target positions, with a trend suggesting this may be greater in people with recurrent NSLBP.

Chapter 4 investigated the accuracy of reproducing random target positions in mid-range of low back forward and backward bending during sitting. In Chapter 5, participants' ability to reproduce a "good" sitting posture was investigated. These studies also showed no differences in the accuracy of low back position awareness, between people with recurrent NSLBP and people without LBP.

The position of "good" sitting posture however, was found to be significantly closer to end-range backward bending (low back extension) in people with LBP (Chapter 5). Although a theoretical relationship of this finding with LBP can be explained, further supporting evidence is needed. In addition, there was a significant difference in total range of forward and backward bending of the low back in sitting between people with and without LBP (Chapter 5).

6.2 Test-retest reliability

Test-retest reliability measurements provide evidence that the electrogoniometer records similar results for measurements on different occasions. In Chapter 2, this related to a comparison of its accuracy to a highly calibrated bevel protractor on different occasions. In the remaining chapters, it was a comparison of whether the electrogoniometer records similar results for measures of position sense of the low back in participants on different occasions.

Before it can be certain a tool is measuring what it is intended, it is necessary to demonstrate that the measurement recorded is reproducible. As reliability involves the ratio of variability between participants to the total variability in measurement scores, a good test for reliability is more likely to occur in a very heterogenous sample (Streiner et al., 2008). It is therefore, more likely that a higher reliability score will occur when there is a greater range of measurements recorded, as was the case in the in vitro testing of the electrogoniometer in Chapter 2. A lower reliability score will occur if the measurements and variability are similar, when there is little difference between measurement errors recorded for position sense for different participants. This was the case in all the in vivo tests reported in the thesis.

This lack of variability in the reposition error recorded for each participant, makes it less likely to find a high reliability score when testing position sense of the low back. It is therefore critically important that the raw data is interpreted in conjunction with the reliability coefficient value. It can be seen from the raw data in the studies in this thesis, that the measurement difference recorded by the electrogoniometer during position sense tests between participants on different days, remains small. The exception been in range of low back sagittal plane movement in sitting in Chapter 5.

Although the study in Chapter 2 validated the electrogoniometer against a highly accurate calibrated bevel protractor, the validation process regarding whether the electrogoniometer can be used to assess position sense in the low back is an on-going process (Streiner et al., 2008).

In chapters 3, 4, and 5, the difference in mean error scores in degrees between day 1 and day 2 were small, for both people with recurrent NSLBP and people without LBP. This may in part be a reflection of the small measurement errors shown in vitro (see section 2:4). It was also found in people without LBP that the mean differences for Bland and Altman tests were smaller and the 95% limits of agreement values were smaller and narrower. In addition, the ICC coefficient value was higher for the test scores on people with no LBP in Chapters 4 and 5, although not in Chapter 3. This difference may be due to the range of error scores been very similar for people without LBP in the tests in Chapter 3, as the less the range of data points on a scale, the poorer the ICC will be and vice versa (Müller et al., 1994). The 95% CI's for ICCs were generally wide and the actual true ICC coefficient value could lie anywhere between the values. This suggests uncertainty as to the true reliability of each of the tests (as measured by ICCs).

Overall the results suggest poorer test-retest reliability of the tests in the LBP group. This may reflect a greater difference in mean error scores and therefore position sense, between day 1 and day 2, for individual participants with LBP. Despite this however, the actual differences in mean error values measured in degrees between day 1 and day 2, also remained very small for people without LBP. As previously mentioned in Chapter 3, all the test-retest results (raw data; Bland and Altman results; ICC values), need to be interpreted together for a better understanding (Rankin et al., 1998).

There is no known "gold standard" measure and test of position sense of the low back, for the participant populations used in the studies in this thesis, and in people in general. The studies in this thesis therefore form part of a validation process for use of the electrogoniometer in measuring position sense in the low back. The studies attempted to see

if there was a difference in position sense between people with and without LBP. Identifying a sub-group of people with LBP, who have a more extreme error in low back position sense, is part of the challenge for future studies. By having two extreme groups one with known greater errors in position sense and one without, would help in assessing validity. Future similar studies therefore, will be needed to develop this validation process (Streiner et al., 2008).

6.3 Size of reposition error

No differences in the accuracy of low back position awareness between people with and without LBP have been reported by other researchers (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000), but some have reported greater position sense deficit in people with LBP (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003). The small position sense errors evident in the studies in this thesis, have been reported in other studies (Brumagne et al., 2000; Swinkels et al., 2000), but similar small errors in people with LBP have been implicated in poorer spinal position awareness (O'Sullivan et al., 2003).

Contrasting interpretation of these findings, suggests that uncertainty exists about the clinical and research significance of small errors in reposition sense. Some authors have reported small mean error differences as significant e.g. between active and passive repositioning tests (0.4 degrees) (Lee et al., 2010; Lönn et al., 2000b), or movement sense between people with and without LBP (0.5 degrees) (Lee et al., 2010), whereas others report similar size differences in error values as non-significant (Lam et al., 1999; Newcomer et al., 2000). There is a need for studies to comment on the clinical significance of small differences in mean error values, rather than just reporting on the statistical significance of any differences found. Comparing P values on their own can be misleading and the additional use of confidence intervals is recommended (Altman, Machin, Bryant, & Gardner, 2000; Matthews & Altman, 1996).

Other possible reasons for discrepancies in findings between studies include: small sample sizes (Descarreaux et al., 2005; O'Sullivan et al., 2003); heterogeneous populations (O'Sullivan et al., 2003); poor "control groups" (Gill et al., 1998; Newcomer et al., 2000); methodological variations in assessment procedures (Brumagne et al., 2000; Descarreaux et al., 2005; Gill et al., 1998; Newcomer et al., 2000); and the number of position awareness tests (Allison et al., 2003). In all the studies in this thesis, a relatively large number of participants were recruited (except for sub-group analysis in manual workers and drivers), with strict inclusion/exclusion criteria for participants with and without recurrent non-specific LBP, and the error of 10 position awareness tests was averaged.

6.4 Study participants

6.4.1 Recruitment of participants

Recruiting participants with and without LBP was difficult. A range of recruitment strategies was used from the onset, including mail shots, posters e.g. in the workplace, GP practices, out-patient physiotherapy departments, and newspaper advertising which was the most effective method in these studies. On reflection, grant applications should have been costed to include weekly use of multiple advertisements in the local free and evening press during the recruitment phases. The benefit of using adverts in local free newspapers, unlike many other recruitment methods, is they are sent to all houses across socio-economic divides within the local community. Recruiting from specific GP practices for example, can lead to selection bias as it restricts recruitment to a particular locality where people may be primarily from one socio-economic group.

In future studies, a wide recruitment strategy with an emphasis on weekly newspaper advertisements throughout the recruitment phase, is most likely to be successful in recruiting the number of participants required to achieve power allowing generalisation of findings.

6.4.2 Pain and disability

Finding no differences in accuracy of position awareness between participants with recurrent NSLBP and people without LBP may reflect the low level of scores for disability and pain in the participants with LBP. People with more severe LBP and higher scores on disability scales, may have greater error in spinal position awareness and additional studies need to be undertaken to investigate this.

6.4.3 Heterogenous population

The population of people with LBP in the studies in Chapters 3 to 5, were primarily those whose episodes of LBP were less than 12 weeks duration. The participants in this thesis therefore did not have persistent chronic LBP as defined by European Guidelines as LBP persisting for at least 12 weeks (Airaksinen et al., 2006). It is possible people with persistent recurrent LBP may have had greater errors in position awareness. There is however, still inconsistency within the literature as to what is the definition of a participant with recurrent LBP, or persistent non-specific LBP. In a systematic review of 43 studies where the populations had recurrent LBP, only 27 studies defined their population. In addition, only 3 definitions for recurrent LBP were used by more than one study and only 11 studies defined the duration of LBP symptoms which ranged from 1 day to 2 years.

There is therefore large variation in the definition of recurrent LBP used in the literature. A consensus on a standardised definition of recurrent LBP is needed to enable appropriate comparisons between studies (Stanton et al., 2010). Even national and international guidelines have used different definitions of persistent or recurrent non-specific low back pain. NICE Guidelines defined a population as suffering persistent or recurrent non-specific LBP, if the LBP persists for greater than 6 weeks, but less than 12 months (NICE, 2009). In European Guidelines, chronic non-specific LBP is defined as LBP persisting for at least 12 weeks. These Guidelines state that the high number of people with recurrent LBP, makes it difficult to distinguish between people with

chronic and acute LBP (Airaksinen et al., 2006). The difference in populations and the terminology used makes it very difficult to compare study findings.

6.5 Measuring position sense

Using an electrogoniometer to measure spinal position and range, can only provide information in one plane (sagittal), whereas movement in the spine is complex, involving associated movements in different planes. Devices such as a spondylometer, that similarly records only sagittal plane movement in the lumbar spine, have also been used successfully to measure and report on spinal movement (Hart, Strickland, & Cliffe, 1974; Taylor et al., 1980; Twomey, 1979; Twomey & Taylor, 1979). Future studies of position sense, could use measuring devices that are able to record movement in all planes of movement (Troke et al., 2001). Whatever measuring equipment is used, it needs to be as unobtrusive as the electrogoniometer, so as not to risk providing sensory feedback on position sense. It will also need to be as simple to set up and to use, in a variety of settings e.g. in the workplace, clinic or research laboratory.

Measuring position awareness over a larger surface area of the spine may be useful. Unfortunately, the size of the electrogoniometer only allowed it to be attached to L1 and the sacrum, with movement at T12/L1 excluded. This might account for differences found between studies, as others reported greatest position sense error at T12 compared to the lumbar spine and sacrum (O'Sullivan et al., 2003). Measuring position sense in the thoracic spine, sacrum and pelvis would also provide more information, although a measuring device with minimal skin contact would be needed, to limit any potential feedback to participants.

6.6 Motion in the spine

Measuring deviations in side flexion, rotation and translation movements in the sagittal plane, would give more information on position awareness. The possible translations (lateral shear, vertical displacement and anterior-posterior shear) however, are small, with forward translations during flexion being the largest at up to 3 degrees. Associated lateral bends and rotation movement of less than 4 degrees during flexion and less than 3 degrees during extension can occur (Pearcy et al., 1984), but are again considered small. It would be unlikely to identify meaningful differences in position sense acuity in relation to these associated movements between people with and without LBP, over and above the error in the measuring equipment and testing protocol.

Although the studies in Chapters 3 to 5 found no difference in accuracy of low back position awareness between people with recurrent NSLBP and people without LBP, the speed and motion characteristics of the back during position sense testing may have been different. Evidence for this has been shown when testing:

- range of movement (McGregor et al., 1997);
- functional movement, which is slower in people with LBP (Simmonds et al., 1998); and
- hand response to a visual stimulus, which is slower in people with LBP (Luoto et al., 1996; Taimela et al., 1993).

These may be better measurements to use when looking at comparisons between people with and without LBP, rather than measuring position sense.

A delayed awareness of spinal posture and movement however, could slow the participants' ability to make appropriate responses to normal or abnormal loading during static and dynamic postures. This would make them vulnerable to injury and pain. Future studies investigating position sense, should therefore investigate the speed and control of trunk movement, when locating a "target" position.

6.7 Protocol used to test position sense

The variability in results within, and between studies, may in part be a reflection on the understanding of the study protocol and subsequent performance of the testing procedure by the participants involved in studies.

6.7.1 Simplicity of position sense tests

The protocols used to test position acuity may have been too simple for people with LBP. It may be that conscious awareness of position sense predominates in these testing protocols, whereas in every day functional activities, segmental reflexes are involved in postural correction (Matthews, 1981; Willigenburg et al., 2010) and these reflexes are effected by pain in the low back (Roberts et al., 1995; Schaible et al., 1985; van Dieën et al., 2003b). When remembering and relocating to the target positions in these studies, their short-term muscle memory (see section 6.8.1) (perhaps provided by conscious awareness from higher centres), appears to have been similar to people without LBP, resulting in no differences in reposition error recordings. This would have positive implications for any short-term treatment effects, as it suggests people with LBP could be trained to find target positions, including an improved low back sitting posture.

Anecdotal evidence from clinical practice, suggests that patients can retain information on low back postures in sitting and during functional movements, such as sit to stand. They appear to be able to recall this at a single treatment session, at follow-up one to two weeks later and at longer follow-up. It remains to be tested however, whether this information can be retained by all patients, in both the short- and long-term.

In the final study (Chapter 5), people with LBP were able to accurately reproduce their “good” sitting posture position, but it was nearer to end-range low back extension. They appeared however, not to have automatic awareness of a more appropriate mid-range “good” sitting posture. It is likely that they would require cognitive thought

processing following advice and feedback from a physiotherapist to achieve this.

In an attempt to make testing harder, a reposition protocol could include visual and audio distraction, as people in chronic pain have poor concentration levels (Dick, Eccleston, & Crombez, 2002). Whether poor concentration levels exist in people with recurrent NSLBP is unknown. This may however, make testing more realistic to the environmental distractions that are occurring in everyday life and could result in greater error recordings in comparison to people with no LBP.

6.7.2 Active reposition versus passive reposition in position sense testing

Active reposition to “target” test positions, as used in this thesis (Chapters 3 to 5), appear to result in consistently small reposition errors in studies (Brumagne et al., 2000; Lee et al., 2010; O'Sullivan et al., 2003; Silfies, Cholewicki, Reeves, & Greene, 2007; Swinkels et al., 2000). By its nature this type of testing involves active movement and therefore the muscle activity and muscle stiffness (see section 1.2.2.3), may heighten proprioceptive feedback to the CNS, due to activation of muscle spindles (Gandevia et al., 1992). Other studies, have compared active repositioning with passive repositioning and reported that the errors associated with passive reposition testing are significantly greater (Lee et al., 2010; Silfies et al., 2007), perhaps due to less activation of muscles and consequently decreased afferent input to the CNS from muscle spindles, during passive testing. Actual differences in reposition error between active repositioning and passive repositioning however, remained small, with the mean differences; ranging from only 0.1 to 0.4 degrees for people with LBP and 0.0 to 0.8 degrees for people without LBP (Lee et al., 2010); and 0.8 degrees in people with LBP and 0.5 degrees in people without LBP (Silfies et al., 2007).

In addition, active muscle testing is considered a test of short-term muscle memory (Lee et al., 2010; Lönn, Crenshaw, Djupsjöbacka, & Johansson, 2000a) and this memory recall may be highly variable

between people, regardless of whether reporting a history of pain or not. Perhaps a better test of the proprioceptive system is to test movement awareness. Some studies have found the errors associated with the ability to sense movement of the trunk show significant differences, with people with LBP detecting movement significantly later than people without LBP. Again, the actual size of the mean differences in degrees only ranged from; 0.3 to 0.5 degrees (Lee et al., 2010); and 0.3 to 0.7 degrees before a fatigue protocol, and 0.6 to 1.8 degrees after a fatigue protocol (Taimela et al., 1999).

Interestingly, no differences have also been found in the perception of movement between people with and without LBP (Silfies et al., 2007). In this study however, participants were young athletes (mean age all participants = 19.5 years), in who proprioceptive changes due to age are unlikely to have occurred (Delbono, 2003; Ferrell et al., 1992b; Hurley et al., 1998a; Pai et al., 1997), and pathological changes due to LBP are unlikely to be extensive.

Unfortunately, the information above suggests variability in results between studies and as such more research is needed before it can be said with confidence as to which test of proprioceptive input is better – either position sense testing or perception of movement testing.

6.7.3 Postural control of the trunk

Postural control and balance is an integration of proprioceptive, visual and vestibular information in the CNS, and impairment has been found in people with LBP (Mientjes et al., 1999; Radebold et al., 2001). People with LBP have been found to sway more than people without LBP when standing on an uneven surface (Brumagne et al., 2008), but paradoxically hold their trunks very stiffly (van Dieën et al., 2003b). This postural strategy relies primarily on proprioceptive information from the lower leg, whereas people without LBP rely on greater sensory input from the back muscles (Brumagne et al., 2008; Claeys et al., 2011; Janssens et al., 2010). This increased postural sway in people with LBP has also been found in sitting, as well as in unstable standing,

and it appears to occur as they struggle to make fine-tuned multi-segmental postural adjustments at the trunk. As postural sway increases, people with LBP may be vulnerable to increased low back stresses and loads. Measuring postural sway in sitting and standing during movement of the trunk and / or limbs, may be a better measure of sensorimotor function than reposition testing alone.

There was a similar finding of a trunk stiffening strategy in 20 participants with a history of recurrent LBP (although not in LBP at the time of testing) when compared to 20 people without a history of LBP (Jones, Henry, Raasch, Hitt, & Bunn, 2012). When standing on a force platform and it unexpectedly moved, there was enhanced activation of the trunk and ankle muscles in people with LBP, consistent with a trunk stiffening strategy aided by increased ankle muscle responses to maintain their upright standing posture.

Decreased variability in postural strategy in the trunk in people with LBP could paradoxically, be a strategy to avoid pain or injury. Biomechanical modelling has demonstrated that a rigid postural strategy reduces movement stresses in the spine. However, this causes increased compressive loading from the trunk muscles and could itself cause pain. Non-normalisation of variability in postural strategy has potential therefore, to be implicated in the cause of recurrent episodes of LBP (Moseley & Hodges, 2006). Future research could investigate a sub-classification of people with LBP (Borkan & Cherkin, 1996) with non-normalisation of variability in postural strategy in the trunk. Furthermore, rehabilitation programmes could investigate whether alterations in postural control can be normalised, and whether this improves levels of LBP and disability. Measuring postural control may give greater insight into sensorimotor function, than testing reposition sense in isolation, as in the studies in Chapters 3 to 5 and others (Gill et al., 1998; Newcomer et al., 2000; O'Sullivan et al., 2003; Swinkels & Dolan, 1998).

The finding in Chapter 5 that people with LBP positioned their perceived “good” sitting posture closer to end range low back extension with

observable bracing of their low back muscles, may be a rigid postural strategy in an attempt to reduce movement stresses in the low back to avoid pain (section 6.10).

6.8 Neurophysiological considerations

There are inherent difficulties in testing position sense. The results represent a combined and variable sensory input from muscles, tendons, skin, ligaments and other joint structures. The tests of position sense, unfortunately, are unable to isolate the input from the different tissues. Furthermore, it is acknowledged that position sense research does not just address proprioception (the afferent pathway), but the sensorimotor system which has both afferent and efferent involvement. It is therefore unknown whether any deficits in position sense are due to problems with the sensory or motor systems, or both. Any deficits found cannot therefore, be soley attributed to problems with proprioception.

Consideration needs to be given to the presence of muscle activity; muscle stiffness and the thixotropic behaviour of muscle (see section 1.1.8). The property of a muscle, such as activity of its muscle spindles, and therefore its ability to sense position, will vary depending on the previous immediate history of its length and contraction i.e. was it previously contracted isometrically, contracted and then stretched, or contracted and then shortened (Proske et al., 2009). Different start positions when testing position sense and different activity levels of a muscle prior to testing, could therefore lead to different position sense responses. A slump sitting start position, as used in Chapters 4 and 5, lengthens the posterior muscles of the trunk. In the absence of the flexion-relaxation phenomenon in people with LBP in sitting (Dankaerts et al., 2006; Mak et al., 2010), the increased activity of the trunk extensor muscles observed, may heighten muscle spindle sensitivity and therefore aid position sense awareness. The length of time in static slump sitting or repetitive exposure to this position however, has an influence on the immediate and subsequent muscle activity during

continued exposure and after exposure (Jackson et al., 2001; Solomonow et al., 2003).

With all this possible variability in muscle response and sensitivity of muscle spindles in relation to the start position and pre/existing history of muscle activity, it is possibly no surprise that there are contradicting results found in the literature regarding the presence or not of position sense deficits in people with LBP. Perhaps, what is important is the length of time in, for example, a slump position – more time in slump may lead to decreased activity of trunk muscles (Jackson et al., 2001; Solomonow et al., 2003) and less sensitivity of muscle spindles. On reflection, a sustained position in slump immediately prior to position sense testing could have lessened sensitivity of muscle spindles and decreased proprioceptive acuity during testing. Whether this would occur similarly in people with and without LBP is yet to be determined.

In the studies in this thesis (Chapters 4 and 5) the start position was slump, but it was a transient start position, preceded by through range tests of range of movements and followed by 10 reposition tests. All these movements could have heightened muscle activity, possibly resulting in heightened sensitivity of muscle spindles and also stimulation of higher centres, resulting in heightened position sense for all participants. Although, the effect of the start position and pre/existing trunk muscle activity prior to position sense testing in people with and without LBP remains unclear, future studies will need to be aware of the possible consequences on the collection of position sense information when designing studies or analysing data.

6.8.1 Muscle memory

Repositioning to a learnt “target” requires recall and may not best reflect the function of everyday unconscious proprioceptive responses that occur in automatic postural adjustments (Claeys et al., 2011). Position sense testing may therefore rely more on short-term memory and processes at a conscious level in the cerebral cortex, than other tests involving movement sense or measures of postural sway.

The study in Chapter 3 in measuring position sense at the elbow was therefore also investigating for the possibility of global difference in proprioceptive acuity that could be attributed to differences in short-term memory and the central processing of proprioceptive information between groups (Gill et al., 1998). As no differences in position sense were found at the elbow, it suggests that these did not exist. If any differences in position sense in the low back between people with and without LBP had been found, it would have implied that the differences in the low back would more likely be associated with a local low back problem, rather than in the processing of proprioceptive information at higher levels in the CNS. As no differences in position sense at the elbow were found and the population studied in Chapters 4 and 5 was similar to those in Chapter 3, it was decided not to repeat the tests at the elbow.

It cannot be said with certainty however, whether differences in central processing or short-term memory exist in any of the people studied in this thesis. More detailed analysis would be required, involving observation of the brain (Matthews, 2004), by possibly using fMRI to improve our understanding of the location of neuronal activity and EEG to inform when this activity occurs (Moseley, 2008b).

The differences found in the positioning of “good” sitting posture closer to end range extension in Chapter 5, may imply a difference in central processing at higher levels in the CNS, although not short-term memory as participants were required to find this position themselves, rather than using short-term memory to initially locate this “good” posture from a previously given “target” position i.e. participants were not initially positioned at this “good” sitting posture by the researcher. Throughout all the studies in this thesis, there was an attempt to control for differences in memory / recall between people with and without LBP, by standardising the amount of time elapsed between remembering the “target” position and the reposition tests (Lee et al., 2010).

Brain imaging will be required to fully understand how short-term memory may be involved in position sense testing. It could be used to investigate how brain processes may differ when processing afferent proprioceptive information on position or movement sense and during automatic postural adjustments (Saper, Iversen, & Frackowiak, 2000). The feasibility of brain imaging during position sense testing of e.g. the low back is questionable, although not impossible with future advances in technology.

6.8.2 Role of peripheral proprioceptors and centrally generated sense of effort, in position and movement sense

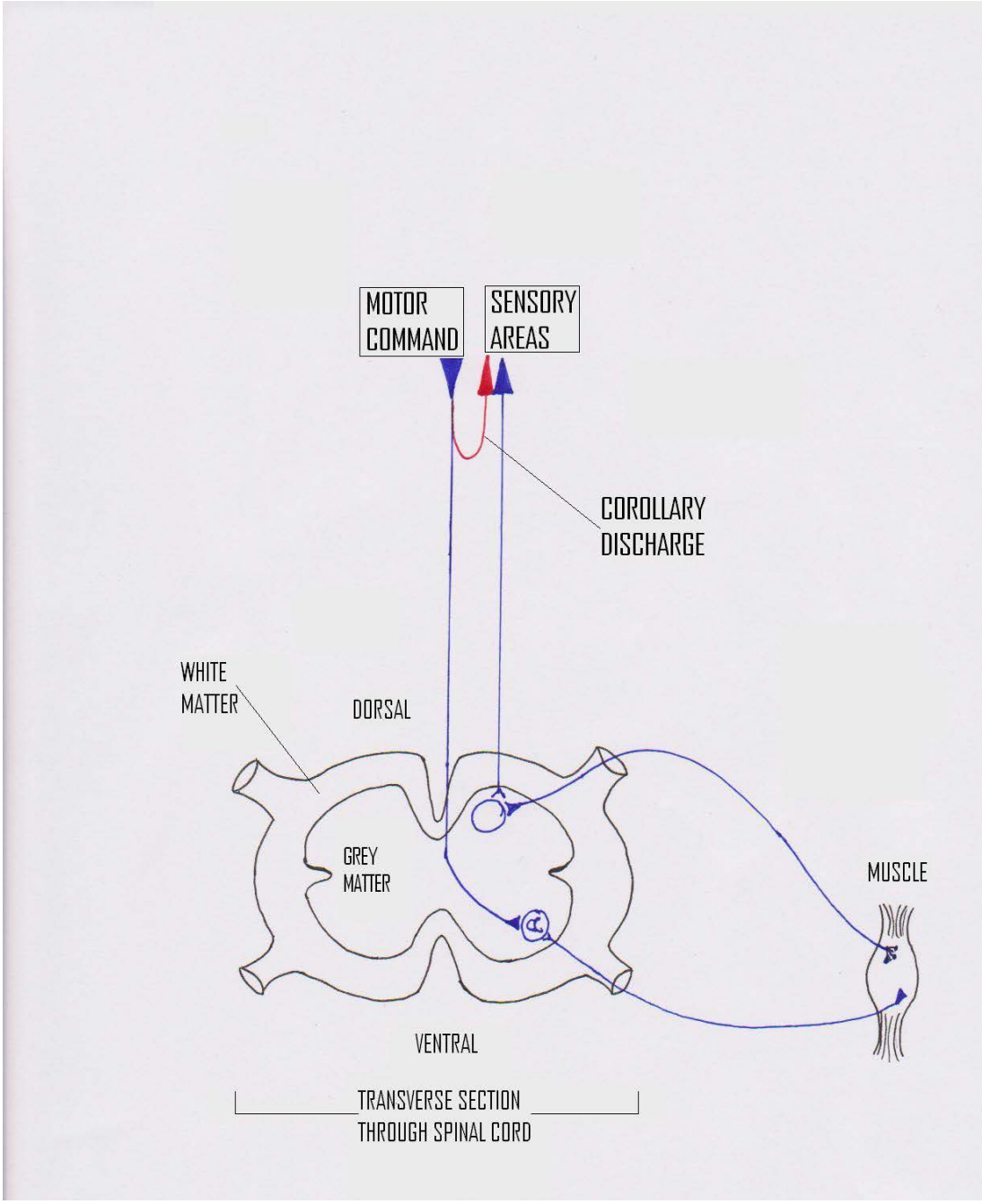
Uncertainty still exists as to how much peripheral proprioceptors contribute to position sense. In 1867, it was proposed that proprioceptive sense did not require peripheral information (von Helmholtz, 1924-25) cited in (Proske, 2006). The will, or effort of movement, led to the sensation of position being generated within the CNS. Subsequently, it was believed that muscles were responsible for providing the afferent information to the CNS (Sherrington, 1907). For much of the 1900s until the late 1960s, joints were considered responsible for providing the proprioceptive information (Boyd, 1954).

In the 1970s, the primary role of muscle in providing position and movement sense was re-established. Research demonstrated that vibration of muscle at 100Hz, through its illusionary effect on muscle spindles, led primarily to illusions of movement and to a lesser extent, deficits in position acuity (Goodwin et al., 1972). More recently, the role of muscle spindles and the skin in providing information on position sense has been popularised, with a less important role given to afferent information which is provided by joint structures (Collins et al., 2005; Grigg, 1994; Johansson et al., 1990; Proske et al., 2009). The studies in this thesis were therefore primarily designed to test the afferent information provided by muscle during through range testing of position sense, particularly around mid-range of sagittal plane

movement. Although no differences in position sense were found between people with and without LBP, these neurophysiological studies suggest that movement sense is worthy of future investigation.

Currently it would appear, that the sense of effort generated in the CNS, in response to positional awareness tasks, may have an important role in providing information on position sense (Gandevia et al., 2006; Proske et al., 2009). In studies that discuss the role of effort, weights have been used to provide loading during testing (Allen et al., 2006). In unloaded or lightly loaded limbs, it is possible that muscle spindles provide position sense. As the load increases, the accompanying muscle contraction with co-activation of the muscle spindles, leads to additional centrally-generated effort signals, which may provide the greater information on position sense (Proske, 2006). Under these conditions it has been suggested that muscle spindles are primarily responsible for movement sense (Allen et al., 2006). It is yet to be determined whether a sense of effort is required for everyday postural tasks, performed by the trunk, when there is no external load. Within the studies in this thesis, the sense of effort was perhaps minimal, as there was no additional loading added to the test movements. It is possible that when the trunk is loaded, for example during lifting, the sense of effort signalled within the CNS may have an important role in position sense, similar to the findings in the limbs.

Research is needed to investigate where in the CNS, this sense of effort information is processed. It is possible that this sense of effort is processed within the spinal cord, from the efferent copy sent from the anterior motor neurons (Figure 1:3), or the generation of the sense of effort in sensory areas of the brain from corollary discharge (Figure 6:1). The exact central mechanism for processing this sense of effort and the link to the motor output, remains to be determined (Proske, 2005). In addition, investigating the sense of effort, functional trunk movement, proprioceptive acuity in the low back in people with and without LBP, poses a challenge to future research.



Key

α = alpha motorneuron

Figure 6:1. Corollary discharge and the sense of effort

Based on Snell (2010), Strandring (2008), Biedert (2000), (Moore, 1987) and (Proske, 2005). A generation of the sense of effort in the sensory areas of the brain from a corollary discharge from the motor command. At sensory level this corollary discharge is correlated with the record of the muscle force actually generated, that is provided by the returning afferent signals. By comparing these, the brain detects any discrepancy and sends information to the motor command to correct this. As the corollary discharge is fed back to sensory areas, the brain is able to use it to generate a sense of effort.

6.8.3 The processing of position and movement sense in the CNS

The studies in this thesis (Chapters 3 to 5) investigated position sense rather than specifically testing movement sense that has been investigated in other studies (Lee et al., 2010; Silfies et al., 2007; Taimela et al., 1999). The CNS mechanism for the unconscious and automatic control of posture and movement involving muscle spindles, and their conscious role in position sense may be separate. There is likely however, to be some interaction of the central processing of relevant information (Proske, 2006). It therefore appears that position sense and movement sense may be processed differently in the CNS (Proske, 2006; Walsh et al., 2004). Studies on monkeys, have suggested that some neurons in the primary motor cortex can switch their response during movement and postural tasks (Kurtzer et al., 2005). Neurons that respond to load during both posture and movement, can rapidly switch their response to loads and movement, during a change from control of posture to movement, or vice-versa (Scott, 2008). This may suggest there are complex, but specialised neural control processes for posture and for movement in the CNS (Kurtzer et al., 2005).

Although in the studies in this thesis, no differences in position awareness between people with and without LBP were found, it is possible that differences in movement sense may exist. This could occur, if as suggested position and movement sense are processed differently in the CNS. Similar studies in the future should therefore incorporate measures of movement sense in the trunk (Lee et al., 2010; Silfies et al., 2007; Taimela et al., 1999).

Although a specific neuron may switch its response to posture and movement, and others respond only to a loading task involving posture or movement (Kurtzer et al., 2005), it has also been suggested that individual neurons in the motor cortex are activated during specific

postures (Graziano et al., 2002). Although the research was carried out on animals, this opens up new areas of study to see if different parts of the human cortex are excited during postural tasks e.g. when adopting a “good” sitting posture as in Chapter 5. Investigating pattern of brain excitation during the testing in this thesis and particularly when adopting a perceived “good” sitting posture may provide researchers with an objective measure to look for differences between people with and without LBP who may adopt different postural strategies. If differences are found between people with and without LBP, research could investigate if the pattern of excitation in the brain could be normalised by rehabilitation of postural awareness.

6.8.4 Pain processes and brain changes

As reported, some studies have found no differences in position sense of the low back (Descarreaux et al., 2005; Lam et al., 1999; Newcomer et al., 2000), whereas others have found differences, between people with and without LBP (Brumagne et al., 2000; Gill et al., 1998; O'Sullivan et al., 2003). The complexity of pain processes may explain why the results in the studies in this thesis do not necessarily concur with others, who have reported poorer spinal position sense in people with LBP. With chronicity in LBP, less nociceptive and non-nociceptive input is required to produce pain and thus, pain itself cannot reliably inform about the processes that occur in body tissues. The motor response of pain is primarily an action to limit the possible aggravation of painful tissue (Moseley, 2003). Thus, the ability to accurately reposition the body may be a mechanism to help prevent further damage to tissues and could remain intact in people with LBP, or at least until changes in sensorimotor processing occurs in the brain due to severity and / or chronicity. What may be of greater difference between people with and without LBP is the speed of accuracy, the muscles recruited and their activity levels, when people attempt to locate target positions during position sense testing.

To better understand the complexity of pain processes, studies should consider the processes occurring in the brain and not just in the periphery. Pain is experienced in the body image held in areas of the brain, like the primary somatosensory homunculus. This “virtual body” is involved in ensuring clear motor commands to coordinate posture and movement (Moseley, 2003). The testing described in this thesis, is likely to have heightened awareness in the “virtual body” for both people with and without LBP, enabling them to focus on each “target” position and making it less likely to find differences in position awareness.

The “virtual body” however, may change in response to ongoing pain with postural and motor responses varying, and becoming less accurate, with changes that are enhanced by a threat and fear of pain (Moseley, 2003). In the studies in this thesis however, the level of pain and disability may not have been severe enough to have led to changes in the “virtual body”. In addition, the threat and fear of pain were reduced by non-threatening, written and verbal explanations, giving assurances that testing involved normal everyday, non-painful and non-dangerous movements. There may also have been a placebo effect and non-specific effects of the environment, such as high-tech equipment in a dedicated research setting. This could in part, explain why similarities in reposition error occurred between people with and without LBP. Similarities in reposition error between people with and without LBP may however, be short-term unless more difficult, deep learning occurs (Sandberg & Barnard, 1997). A protocol involving teaching e.g. a “good” sitting posture to people with and without LBP, and then investigating their ability to reproduce this position at timed intervals on the same or different days, would test level of learning, muscle memory and ability to recall.

Depression is commonly associated with musculoskeletal pain (Dick et al., 2002), and may also contribute to sensory changes (Wand, O'Connell, & Parkitny, 2010a). The sensory changes refer commonly to pain perception, but are not consistent or fully understood and may

vary between experimentally induced pain and chronic pain states (Dickens, McGowan, & Dale, 2003). Any possible association however, between depression and sensorimotor awareness, including position sense, warrants further investigation. Depression was not measured in the studies in this thesis, because of being unaware, when designing the studies, of the possible link with sensorimotor awareness. It is unknown whether higher levels of depression in people with or without LBP would have led to increased errors in position sense, or whether a combination of LBP and a high level of depression would lead to greatest error. If depression was associated with alterations in acuity of position sense, the cortical mechanisms involved could be similar to those associated with threat and fear, with central changes like heightened sensitivity of the pain neuromatrix (a combination of cortical mechanisms activated during pain) described by Moseley (2003), leading to alteration in the "virtual body" image in the brain. Future studies could investigate for an association between measures of depression and position sense in people with and without LBP.

In chronic pain, representation of body parts and movement is altered in the primary sensory and motor cortices, affecting sensory awareness and motor outputs (Lotze et al., 2007). For example, studies suggest people in pain are less able to identify the location and features of tactile stimulation applied to their painful body part. This is associated with reorganisation in the primary somatosensory cortex (Maihöfner, Handwerker, Neundörfer, & Birklein, 2003; Maihöfner et al., 2006; Moriwaki et al., 1999). It is possible that in the studies in this thesis, pain levels and disability were not severe enough to result in these changes in the brain.

In complex regional pain syndrome, discrimination training showed immediate improvements in tactile acuity (an indicator of primary sensory cortex organisation), lasting up to three months (Moseley, Zalucki, & Wiech, 2008) and in phantom limb pain improvements in cortical reorganisation remaining at three months (Flor, Denke, Schaefer, & Grüsser, 2001). The studies however, were small and

stimulation was applied to only small areas of skin related to their pain and these were not investigations in LBP. Their findings may suggest however, that similar training on postural or movement awareness in people with LBP, could potentially result in improvements of proprioceptive acuity. Studies should be designed to investigate this in people with decreased position / postural awareness due to LBP.

The above finding that discrimination training resulted in immediate improvements in tactile acuity may have similarities to the research in this thesis, although a very specific and localised tactile awareness was required in their studies. The testing protocols described in this thesis required participants to heighten their awareness of very precise static postures, subtle movements of the low back and trunk muscle activity. This may have helped the ability of all participants (LBP and NLBP) to discriminate between the locations of the target positions. The cortical mechanisms involved, may be similar to those in successful discrimination training, where it is believed that improved reorganisation in the primary somatosensory cortex occurs (Flor et al., 2001; Moseley et al., 2008), with normalisation shown on resolution of symptoms in complex regional pain syndrome (Pleger et al., 2005). In the studies in this thesis, reorganisation of the primary somatosensory cortex may even have already occurred in people who had resolution of their low back symptoms at the time of testing, thus improving their performance in the reposition tests, however, this is unknown.

There is evidence in people with chronic LBP, that patients drew distorted body images of their trunk (Moseley, 2008a) and that two-point discrimination was also diminished in the low back in people with back pain (Luomajoki et al., 2010; Moseley, 2008a; Wand et al., 2010b). This localised disruption in body image and of two-point discrimination is likely to be related to alterations in the sensory input from the area (including proprioceptive), with cortical representation (a body map) of the back in people with LBP different to healthy controls (Flor et al., 1997). There is however, a larger representation on the primary sensory cortex in contrast to people without LBP and to other

painful conditions like complex regional pain syndrome (Maihöfner et al., 2003) and phantom limb pain (Moseley, 2008a). How alteration of two-point discrimination and an absence or disruption when drawing their body image, and the larger representation on the primary sensory cortex in people with LBP, relates to position sense awareness in the back, needs investigating. It could explain why people with LBP had altered awareness of a “good” sitting posture (Chapter 5), but does not explain why no differences were found in acuity of position sense between people with and without LBP (Chapters 3 to 5). It is possible that acuity in these studies remained accurate, because of the larger cortical representation of the back on the primary sensory cortex, in contrast to people without LBP and other painful conditions (Flor et al., 1997; Maihöfner et al., 2003; Moseley, 2008a).

The small representation of the trunk on the sensory homunculus (Figure 1:5), suggests a less important role for afferent input from that area. Conversley, there is a large area of the cortex that receives sensory information from the hand and lips, and also from the limbs. Any differences in proprioceptive acuity, in for example the lower limb, between people with and without pain, may be more easily identified due to the higher level of importance given to the sensory information from this area. Consequently, it may be more difficult to investigate differences in the conscious awareness of position sense in the back, regardless of whether or not people experience LBP. This needs to be considered when planning future studies aiming to investigate position sense in the low back.

In addition, decreased corticospinal excitability has been demonstrated in people with chronic LBP (Strutton et al., 2005) and in people with unilateral sciatica (Strutton et al., 2003). It is unknown whether this decreased corticospinal excitability is an attempt to relax the muscle close to the site of pain, to help lessen symptoms. Alternatively, this change may suggest altered control of the back muscles that could lead to LBP. In the studies in this thesis it is uncertain whether differences in corticospinal activity existed between people with and without LBP. It

is possible that any differences, if they existed, were small due to the low levels of pain and disability experienced by the people within these studies.

Studies suggest that motor skill training can increase excitability of the motor cortex in the cortical area for the leg in healthy non-pain individuals (Perez, Lungholt, Nyborg, & Nielsen, 2004). Studies are needed to investigate for changes in excitability in people with LBP following rehabilitation and whether this results in subsequent decreases in pain. A preliminary study suggests that two weeks of motor skill training, involving isolated voluntary contractions of TrA, can reverse motor cortical changes in 20 people with recurrent LBP (Tsao, Galea, & Hodges, 2010). It is possible that the controlled and repetitive nature of the spinal movements used to locate target positions that were utilised in this thesis, may have enhanced or normalised corticospinal excitability in people with LBP. This is pure conjecture as there is no certainty that any changes in corticospinal excitability existed, however it could explain why during testing there were similarities in reposition error between people with and without LBP.

To gain a greater understanding of cortical involvement in position awareness, future research should include brain imaging to investigate whether differences in brain activity exist between people with and without LBP. The location of neuronal activity in the brain can be investigated using fMRI and TMS (Moseley, 2008b; Strutton et al., 2003; Strutton et al., 2005; Tsao et al., 2008a), whereas EEG better informs about when it occurs (Moseley, 2008b).

6.9 Trunk muscle function

Altered trunk muscle function in people without LBP

A potential reason for not finding differences in position awareness (Chapters 3 to 5), may be that altered trunk muscle function is present in asymptomatic people who later go on to develop LBP (e.g. within two years) and in people with no LBP who have neck pain (Moseley, 2004). In this study, poor ability was found in an abdominal drawing-in task, recorded in prone lying using pressure biofeedback. It is unknown whether the participants in the studies in this thesis with no LBP, had either altered trunk muscle function or neck pain. If they did, and as muscle is a major "informant" of position sense, this could in part explain why no differences in position awareness were found in the studies in this thesis.

Interpretting trunk muscle function solely on performance using a pressure biofeedback machine is perhaps questionable in the research setting, in the absence of other quantitative information from e.g. EMG. Furthermore, the asymptomatic people in the study by Moseley (2004) were only asked about LBP in the preceding two years and could have had previous LBP leading to altered trunk muscle function.

Measuring trunk muscle function, using e.g. EMG as an adjunct to position awareness testing would enable investigation of any potential link. It was recently reported that participants with non specific chronic LBP who had significantly greater error when repositioning to a therapists identified neutral sitting posture, when compared to people without LBP, also had significantly higher muscle activity recorded with surface EMG of external oblique and the transverse fibres of internal oblique (Sheeran et al., 2012). The activity of the superficial lumbar multifidus, showed no differences between people with and without LBP. This remains an area requiring further investigations.

Fear of pain, (re)injury and mental stressors

Fear of pain and (re)injury (Vlaeyen et al., 1999; Watson et al., 1997a) and mental stressors (Flor, Turk, & Birbaumer, 1985) can affect trunk muscle function during movement (Figure 6:2). Any alteration in trunk

muscle function could alter the sensory feedback informing position sense or the motor output response. This could lead to possible alterations in acuity of low back position awareness in either people with or without LBP. Unfortunately, no measures of these fears or stresses were recorded in the studies in this thesis. It is therefore unknown, whether for example, people with LBP (who had relatively low scores for disability and pain), had relatively low levels for these factors resulting in less detrimental effect on their trunk muscle dysfunction and consequently, their ability in the reposition tests. The people with LBP in the studies in this thesis may primarily fit the right side of the model (Figure 6:2), i.e. low fear, leading to recovery. They therefore, would not have suffered the abnormal movement behaviour and associated effects on muscle function predicted by the left side of the model. This could be a further explanation of why no differences in position awareness were found, between people with and without LBP.

Studies rarely comment on how fear of pain and (re)injury (Vlaeyen et al., 1999; Watson et al., 1997a) and mental stressors (Flor et al., 1985) can affect trunk muscle function during a testing procedure. In biomechanical modelling studies where these stresses do not exist, it is suggested that decreased activation of the deep trunk muscles may decrease fine, segmental control of the spine (Wilke et al., 1995) and lead to less feedback on postural awareness. In people with LBP, increased activity of the superficial back muscles also occurs (van Dieën et al., 2003a) as a protective strategy, thereby limiting stresses and movement of pain-sensitive / injured tissue in the back (van Dieën et al., 2003b) that are particularly vulnerable to flexion loading. This is consistent with finding less range in low back sagittal movement (Chapter 5) and potentially supports the belief that loss in range was primarily a loss in low back flexion (see section 5.7.2 and 5.7.3).

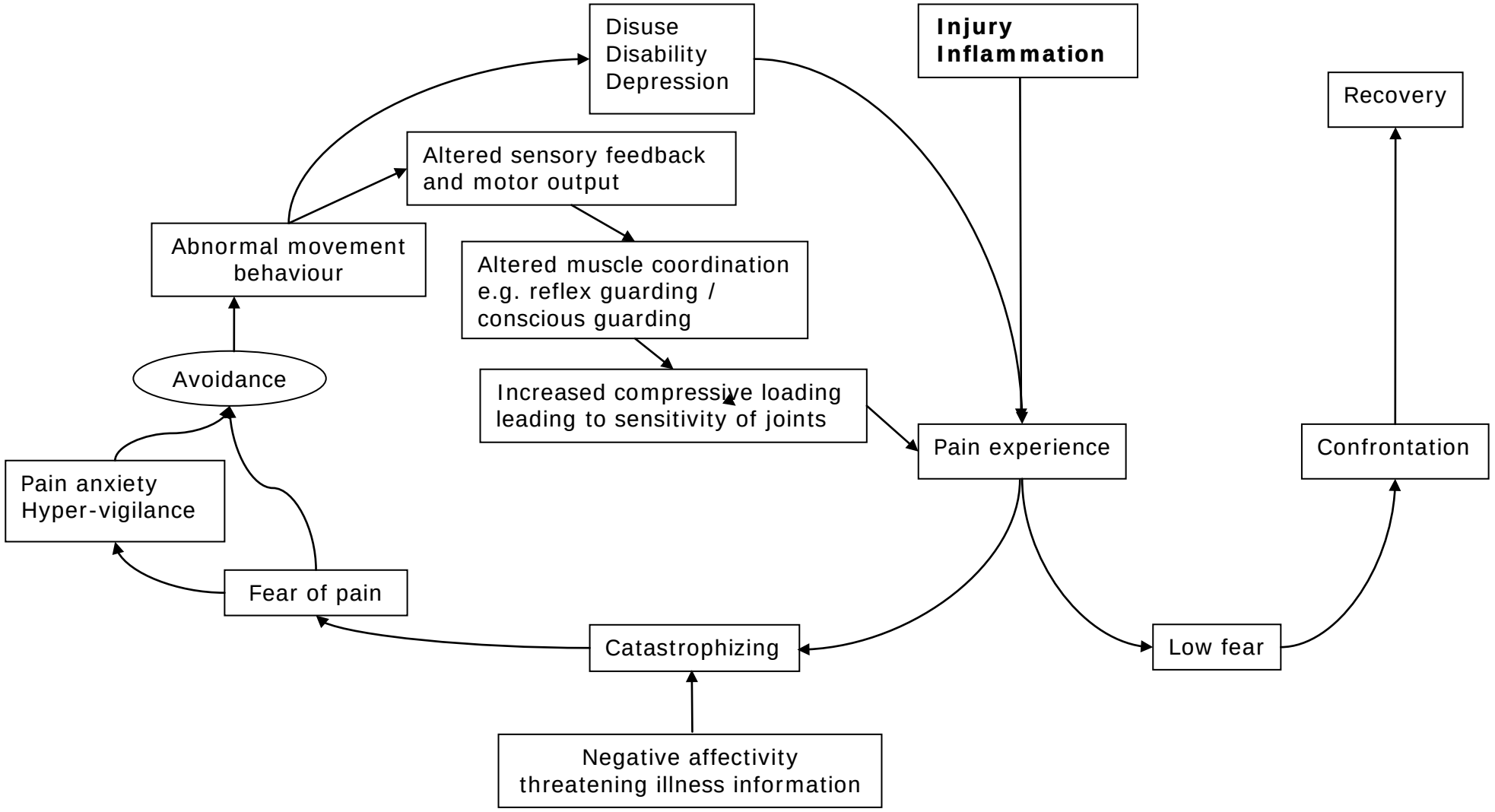


Figure 6:2. Fear avoidance model of pain & possible effect on muscle. Based on fear-avoidance model of chronic pain (Leeuw et al., 2007), fear avoidance model (Vlaeyen & Linton, 2000) and fear-anxiety-avoidance model (Asmundson, Norton, & Vlaeyen, 2004).

CNS control of lumbar trunk muscle activation

Alterations in the nervous system control of the lumbar trunk muscles in people with chronic LBP (Radebold et al., 2001; Sihvonen et al., 1991; van Dieën et al., 2003a), will affect sensorimotor function including postural control and movement awareness. There is a lack of consistency in the affect of LBP on trunk muscle fuction. Studies have suggested that bilateral activation of TrA is delayed in people with LBP during single rapid arm movements and was not dependent on the direction of arm movement (Hodges, 1999). This was also found during remission from back pain (Hodges, 2001). Contrastingly, ultrasound tissue Doppler-imaging in people with LBP found no delay in TrA feed-forward activation during arm movements (Gubler et al., 2010), although others report delayed activation in the deep lumbar multifidus in people with LBP (MacDonald et al., 2009).

Others suggest that anticipatory activation of TrA is direction-dependent as it was found to occur earlier for shoulder flexion (Mannion et al., 2008), suggesting a primary role in anticipatory postural adjustments. Rather than a bilateral activation of TrA occurring with arm movement, it is reported that contralateral activation occurs in healthy individuals with no LBP. This is consistent with anticipatory postural adjustments rather than a specific spinal stability role, that would require bilateral activation of TrA (Allison et al., 2008a; Allison et al., 2008b).

A lack of consistency in the findings of different studies, suggests variable trunk muscle activation occurs in people with LBP, and studies combining EMG with ultrasound tissue Doppler-imaging would aid understanding of an anticipatory feed-forward role for the deep trunk muscles. The deep trunk muscles have an important role in position sense and it is possible that if delayed anticipatory activation of TrA is not a consistant finding in people with LBP, then reposition error may be similar to people without LBP (Chapters 3 to 5). Errors may become more prevalent if this muscle is subjected to fatigue (that affects its anticipatory action), particularly in people with LBP and if pain leads to alterations in trunk muscle function at multiple spinal levels.

Any delayed onset of the deep trunk muscles such as the short, segmental fibres of multifidus, are said to primarily occur on the side of current or previous LBP (MacDonald et al., 2009). This is consistent with morphological changes found in the deep fibres of multifidus on the side of symptoms (Hides et al., 1994). These deep fibres are believed to contribute more than two-thirds of the control of intersegmental movement in the low back (Wilke et al., 1995). In the studies in this thesis, LBP did not affect participants' ability to locate their target positions, but where pain was predominately one-sided, the contra-lateral multifidus and multifudus at other spinal levels may have compensated for any loss of sensory information about spinal position.

This is possible because there is an extensive neural network in the muscle spindle system suggesting that individual muscle spindles are influenced by activity throughout the muscle spindle population. This system may be most suited for sophisticated coordination between parts of a muscle or even different muscles (Appelberg et al., 1982; Johansson et al., 1991b). Thus, if a muscle is injured or affected by LBP, proprioceptive information may be substituted from non-affected muscle spindles in another part of the same or different muscle, on the same or opposite side of the body. As a result, deficits in position sense in the low back may be hard to find when testing people with LBP. It is more likely that alterations in low back position acuity would occur in people who have multi-level, bilateral morphological and timing changes in multifidus and other muscles like TrA. Unfortunately, this information was not collected, which on reflection was an oversight, but future studies should consider using ultrasound or MRI to investigate morphological changes and EMG to investigate for delays in timing.

Rehabilitation of trunk muscles in LBP

The deep back muscles have a crucial role in normal segmental control in the low back (Wilke et al., 1995). Exercise programmes aimed at restoring activity of the deep trunk muscles and spinal control have restored the cross-sectional area of multifidus, thereby decreasing

recurrent episodes of LBP (Hides, Jull, & Richardson, 2001; Hides et al., 1996). It has also been shown in people with LBP and spondylolisthesis, that an exercise programme decreases pain and improves function (O'Sullivan et al., 1997b). As the deep muscles, like multifidus and TrA, are rich in muscle spindles, proprioceptive awareness including location of “good” sitting posture may have also improved in the people with LBP in these studies, although this remains unknown.

A study involving nine people with LBP who undertook isolated voluntary activation of TrA at two sessions (initial and two weeks) and also training at home twice per day for one month (Tsao & Hodges, 2008b), reported earlier onset of TrA as recorded by needle and surface EMG of the trunk during rapid arm movements. These changes were retained at six months in most participants, suggesting a persistence of motor training response. This earlier activation of a feed-forward mechanism may be a response to training by the CNS (e.g. sensorimotor cortex and cerebellum) and enable the body to better prepare for postural adjustments and dynamic movement (Tsao & Hodges, 2007). It suggests improvements in proprioceptive afferent information may occur in people with LBP following active training of muscles in the low back, and this is likely to improve the feed-forward mechanisms. Specific measures of position and movement sense however, would need to be collected before this could be said with certainty. Whether these changes in feed-forward mechanisms are associated with improvements in proprioceptive acuity, and whether they would relate to improvements in pain and disability in LBP, are yet to be determined.

6.10 "Good" sitting posture and end-range

Much LBP is considered to be due to injury to the disc or ligaments, because of overloading (Adams & Dolan, 1997; Panjabi, 2006; Pope et al., 2002). This can have a detrimental effect on spinal posture and movement control and can cause increased segmental movement of the spine (Kaigle, Holm, & Hansson, 1995; 1997; Schmidt, Howard, Lim, Nowicki, & Haughton, 1998). Injury to the deep ligaments of the low back, can result in activity of multifidus in an attempt to stiffen the local segmental level (Solomonow et al., 1998). It is known however, that this muscle can become wasted by pain local to the segment and side of injury (Hides et al., 1994) and delayed activity occurs (MacDonald et al., 2009). In this scenario, the more superficial trunk muscles are believed to increase their activity and co-contract in an attempt to improve spinal stiffness (van Dieën et al., 2003b) and limit painful spinal movement.

Although we had no definitive diagnosis of the pathological processes involved in the people with LBP and did not measure muscle size or activity, this increased activity of superficial back extensors and bracing of the low back, may be similar to what was seen in the study investigating the position of "good" sitting posture to end-range low back extension (Chapter 5). In hindsight, it would therefore have been useful to have had a quantitative measure of muscle activity. Greater reliance on superficial back extensors for feedback of sitting posture, could cause people with LBP to position their "good" sitting posture closer to end-range extension in an attempt to splint their back, to limit potential for provocative movement, particularly in flexion. The superficial back muscles provide a coarser, more global and rigid control that can be responsible for ongoing pain by their increasing compressive loading on pain-sensitive spinal tissue. A person's belief about their back pain may also lead to, or maintain, these alternative protective strategies (MacDonald et al., 2009; Moseley et al., 2006; Moseley, Nicholas, & Hodges, 2004a), with changes in control of the deep back and abdominal muscles persisting even when their current

LBP subsides (Hodges et al., 1999; MacDonald et al., 2009; Moseley et al., 2006). Better activation of the deep trunk muscles, to improve fine control, would potentially help lessen activation of the superficial back muscles.

The position of a perceived "good" sitting posture to the end of sagittal range, could therefore have an important relationship with LBP. Another study has found in patients with flexion related LBP, that their "usual" sitting posture is closer to end-range flexion than people with no LBP. It was found to be within 6 degrees of their end-range flexion (O'Sullivan et al., 2006).

"Ideal" sitting posture in people with no LBP is reported to be between 65 to 70% of total range when 100% is full extension and 0% is full slump (O'Sullivan et al., 2010). Whether the location of this "ideal" sitting posture is similar to the "good" sitting posture in the current study is uncertain, as direct comparison is difficult due to methodological differences e.g. equipment used and their measures were between L4 to S1 (against L1 to S1 in the studies in this thesis).

The finding in Chapter 5 that people without LBP positioned their perceived "good" sitting posture 16.51 degrees from end-range extension, whereas in people with recurrent NSLBP this distance was 12.47 degrees, may have implications for LBP. An in vitro biomechanical modelling study reported muscle forces significantly increase from 1N/m at a neutral lordotic posture (located at 16 to 20 degrees from an excessive lordosis), to 50N/m at an excessive lumbar lordosis (Shirazi-Adl et al., 2002). The associated increases in muscle forces that occur as this sitting posture gets closer to end-range extension, may therefore lead to increased compressive loading on pain-sensitive structures.

This comparison between studies should be read with caution as no other data are available to allow any attempt at comparing people with LBP from other studies. The only similar study comparing perception of "good" posture between people with and without pain investigated this in the neck (Edmondston et al., 2007). This study also found significant

differences in the perception of “good” posture in relation to head tilt and head protraction, between people with and without neck pain. Similarly, there was no difference in the proprioceptive acuity of people with and without neck pain when repositioning to their “good” posture.

Some success has been reported in identifying patient’s who have a lack of segmental stability in the lumbar spine, where pain-sensitive spinal tissue can be excessively over-loaded by end range postures. Lumbar segmental instability is considerd as a significant sub-group within people with chronic LBP (O'Sullivan, 2000). Two main clinical patterns (“flexion” and “extension”) are identified, based on the directional nature of injury and people’s low back position during static postures and movement. In both, there is a tendency for people to brace their backs in extension. In the “flexion” pattern, although a loss of low lumbar lordosis occurs, there is also a compensatory lordosis in the thoracolumbar spine (Figure 6:3). In the “extension” pattern, the spine is in increased lordosis. This extension of all or part of the low back may again, be an attempt to stiffen the spine to gain postural stability by recruiting the larger superficial back muscles. This is consistent with the finding that people with LBP positioned their “good” sitting posture closer to end-range extension (Chapter 5) and visually held much of, or their entire lower spine in lordosis. Unfortunately, the study did not measure segmental movement of the spine, so it cannot be said with any certainty, whether these patterns existed in the participants and where exactly, extension occurred in the low back.

Similarly, patients with chronic LBP have been classified into a mechanism based system of “movement” impairment or “control” impairment. These may also present in a directional manner and commonly an active extension pattern or an active flexion pattern exists (O'Sullivan, 2005).

Figure 6:3. Flexion pattern with compensatory thoracolumbar lordosis

Investigating clinical sub-groups (O'Sullivan, 2005; O'Sullivan, 2000), and people's awareness of "good" sitting posture and the position of "usual" postures to the end-range of spinal movement, is important for clinical practice and clinical research. A study of twenty-six patients with chronic LBP (Vibe Fersum, O'Sullivan, Kvåle, & Skouen, 2009), has demonstrated moderate to substantial inter-tester reliability between four physiotherapists, in identifying patients based on this mechanism-based classification system (O'Sullivan, 2005). This research suggests that treatment could be directed towards specific sub-groups of LBP. Management strategies should aim to improve awareness of "good" postures and awareness of movement, during dynamic functional tasks, to off-load spinal tissue from repetitive movement stresses, including end-range loading. Reports in peer reviewed publications of the success of this approach, in randomised clinical trials of physiotherapy for specific sub-groups of people with LBP and movement control impairment, are awaited (Fersum, 2011; Saner, Kool, de Bie, Sieben, & Luomajoki, 2011).

7 LIMITATIONS OF THE RESEARCH

Neurophysiological studies and sensorimotor control

There are problems with designing studies to investigate position sense in the low back:

1. The neurophysiological mechanisms involved in sensorimotor control are still not fully understood, particularly in the CNS. Uncertainty still exists as to the relative contribution made by peripheral proprioceptors and centrally-generated information (Chapter 1 and section 6.8.2).
2. The skin or other muscles not affected by low back pain and also centrally generated information, may compensate for any loss of position sense that may occur in people with LBP (sections 1.1.3; 1.2.2.3 and 6.8).
3. The neurophysiological studies, on which theories about sensorimotor control are based, are often small scale and are commonly on animals (Chapter 1). Human studies have often been done in the limbs, where it is possible that greater deficits in position sense occur (section 1.1.3).
4. The neurophysiological studies on position sense in the human trunk, have largely investigated the effect of vibration on muscle spindle sensitivity (Brumagne et al., 2000; Brumagne et al., 1999b) (sections 1.2.2.3 and 1.2.6.1). Whether the findings of neurophysiological studies in animals or the limbs in humans, occur in the trunk, is largely yet to be determined.
5. Uncertainty remains about whether there are changes in the sensitivity of muscle spindles in LBP (Clark et al., 2011; van Dieën et al., 2003b; Zedka et al., 1999), and consequently their relationship to position sense in people with LBP is still not fully understood (section 1.2.2.3).
6. Consideration needs to be given to muscle activity levels, stiffness characteristsics and thixotropic property of muscle in people with and without LBP, and the effect of start position, pre-movement tests and the movement tests themselves on these properties and the subsequent consequences for awareness of position sense (sections 1.1.8 and 6.8).

Defining the LBP population

1. The population of people with LBP were primarily those whose recurrent episodes of LBP were less than 12 weeks duration. Only two participants with LBP had a history of an episode of LBP lasting greater than 12 weeks in Chapter 3 and two in the study in Chapters 4 and 5. The participants in this thesis therefore did not have persistent chronic LBP as defined by European Guidelines as LBP persisting for at least 12 weeks (Airaksinen et al., 2006). It is possible that a population of people with more persistent LBP may have had greater errors in position awareness (see section 6.4.3 for discussion related to the differences in definition and terminology used in studies when describing people with LBP).
2. In hindsight it would have been desirable to define the population of people with LBP before recruitment and just recruit either participants with acute, sub-acute or chronic LBP. It was a pragmatic decision to recruit people with recurrent NSLBP, because of the difficulties associated with recruiting participants for research and a desire not to limit the size of the LBP population. If the studies for example had only recruited those with chronic LBP defined as a 12 week history, only two participants would have been recruited in the study in Chapter 3 and two in the study in Chapters 4 and 5.

Heterogeneous population of people with LBP

1. The heterogeneous nature of LBP in the patients in this thesis is a possible limitation. A study that identified a homogeneous specific population of people with LBP found significant differences in spinal position awareness between participants with and without LBP (O'Sullivan et al., 2003). Unfortunately, classification of people with LBP into sub-groups in this thesis was not possible. The specific diagnoses for participants' were unknown, thus preventing retrospective analysis of position awareness based on sub-classification of the participants with LBP.

Difficulties with recruitment in Chapter 3

1. The main limitation occured when considering the secondary analysis of the manual workers and drivers occupational sub-groups, as the sample size was too small. Only the sedentary group achieved the sample size required for power.
2. A major cause of slow recruitment of drivers was probably due to them being self-employed and this made it difficult for them to attend for testing, as it impacted upon their income. A major cause of lack of recruitment in manual workers was probably due to the lack of industries locally, with a bias towards sedentary work in the local economy.
3. Recruiting participants with NLBP proved additionally challenging, because as they had never had back problems, they had no health incentive to participate. In addition, because LBP is so prevalent, identifying participants without LBP is difficult.
4. Although a variety of recruitment strategies were used: mailshot and posters, radio interview broadcast on local BBC Radio; the newspaper adverts published in the local evening newspaper and free newspapers proved to be the most successful method of recruitment. These were expensive however, and money had to be found from within the limited resources of the grant, which prevented additional advertisements. For the study in Chapters 4 and 5, newspaper adverts were therefore the preferred method of recruitment with the cost covered by dedicated funding within a research grant award.

Disability and pain scores

1. The disability and pain scores of the participants with LBP on the days of testing were low, indicating they were not severely affected at the time of testing. The sample population throughout this thesis are probably unrepresentative of people with more severe LBP, in whom error in spinal position awareness may be greater. On reflection a minimum criterion of

4 points for RDQ on the day of testing could have been set as this is recommended for participants entering clinical trials in order to detect meaningful improvements following intervention (Stratford et al., 1996). Participants would therefore have been more representative of patient populations used in clinical intervention studies, making the results more relevant for researchers and clinicians.

2. In studies of this nature, people who are fear-avoiders and who may therefore report higher levels of disability and pain are unlikely to volunteer. It is perhaps not surprising that the scores for disability and pain were relatively low. An entry criterion with a minimum score for disability and/or pain scores on the day of testing or in the preceding weeks would be helpful in ensuring that those participants who are minimally affected by their LBP are not included in studies.

Use of the electrogoniometer to measure position sense

1. The results in Chapter 2 demonstrated that the electrogoniometer equipment was accurate to within a range of 0 to 0.50 degrees of mean error for testing between +/- 60 degrees. This was considered an acceptable level of accuracy and is comparable to other equipment that could have been used. The mean errors in position sense, found in people with recurrent NSLBP and those without LBP were well in excess of the maximum mean errors found in the electrogoniometer equipment itself.

2. The results of this thesis only relate to the use of the back electrogoniometer (flexible M180B electrogoniometer, Biometrics Ltd, Gwent, UK), and its use over a range of 0 to +/- 60 degrees. This range was in excess of the range of low back movement tested in Chapters, 3, 4 and 5. In addition, the results only reflect the specific electrogoniometer that was used throughout the studies in this thesis. Whether the results would be similar for other back electrogoniometers is unknown, although others

have found the results to be similar when testing a number of different M180 electrogoniometers used to measure other joints (Rowe et al., 2001).

3. There are common limitations associated with measuring equipment attached to the skin such as skin movement, defining the angles to be measured and the centre of rotation in participants. To accurately measure movement, imaging such as X-ray and/or CT scan, may be the best comparative measure. These however, have risks associated with radiation and do not allow easy measurement of functional movement. Studies however, have also shown that measurement of spinal movement with skin markers is valid (Gracovetsky et al., 1995).
4. Although the electrogoniometer was compared to a known angle measure using a calibrated bevel protractor and found to be a valid and reliable measure (see Chapter 2), no such comparison was made when measuring in people with and without LBP. Conventionally, criterion validation is the correlation of a scale, ideally to a “gold standard” measure. This process is known as concurrent validation e.g. a study to correlate the new scale with the criterion measure, with both measures to be completed at the same time (Streiner et al., 2008). Unfortunately, there is uncertainty as to what would be considered a “gold standard” measure of position sense in the low back. In addition, availability of possible comparative measuring equipment was limited and others use variable reference points when collecting data e.g. a piezoresistive electrogoniometer applied only to the sacrum (Brumagne et al., 2000; Brumagne et al., 1999b), and completely different measuring scales e.g. the Fastrak electromagnetic device measures anteroposterior and superoinferior translations and have been reported in centimetres (O'Sullivan et al., 2003).
5. There needs to be certainty that a measure used in any comparison is truly a “gold standard”, as often they may have gained criterion status over time, but have less than ideal

validity and reliability. More often than not there is a need to have numerous experiments over time, before there is sufficient evidence for the validity of a measure. In addition, a reliability coefficient only refers to a specific population (Streiner et al., 2008). Therefore, the same population needs to be tested in numerous experiments to gain greater insight into the reliability and validity of a measure.

6. It is acknowledged that no “gold standard” was used to ensure the accuracy of identifying the sacrum and L1 in this research. Therefore uncertainty exists as to the validity of this assessment. Only by the use of X-ray analysis would it be possible to absolutely confirm the segmental location which would not be possible due to logistical or ethical reasons because of the exposure to radiation for participants. In an attempt to negate these difficulties and difficulties associated with inter-therapist reliability, the researcher was the only person attaching the electrogoniometer and also took all measurements on all participants to ensure consistency of the testing procedures (Gonnella et al., 1982; Matyas et al., 1985; Panzer, 1992; Seffinger et al., 2004). The researcher has clinical and research experience in these approaches, and has previously published work investigating the accuracy in locating of lumbar spinous processes. Movement at L5/S1 was confirmed by palpating intervertebral movement during active movement in the sagittal plane during sitting and standing. The researcher then counted up from the sacrum to locate the L1 spinous process. In addition, the protocol for locating the spinous process followed a method based on the shapes and sizes of the spinous processes, that was shown to improve accuracy of manual examination of the low back (Phillips et al., 2009). On reflection it is acknowledged that a test of the the reliability of the researcher in this manual examination procedure would have been desirable. Perhaps, the use of ultrasound imaging may help in confirming the accuracy of identifying the spinous processes (Tshui-Hung, Saber-Sheikh, Moore, & Jones, in press).

Motion of the spine and measurement of position sense

1. Although position sense was reported in the sagittal plane, it is acknowledged that the spine does not just move in a single plane. Motion occurs in multiple planes and translations, and analysis of these would provide more accurate information on proprioceptive acuity. Position sense was recorded in the sagittal plane however, to minimise the potential for measurement error due to "crosstalk" (Jonsson et al., 2001; Rowe et al., 2001) (see section 2.5.1). Errors can become substantial if the electrogoniometer moves excessively in another plane at the same time e.g. during side flexion or rotation. This "crosstalk", would effect the validity and reliability of the electrogoniometer and was consequently avoided during testing on people with and without LBP in this thesis. Once baseline data are collected on sagittal plane movements, further work could be undertaken to determine the involvement of other planes of movement in low back position sense.
2. Other apparatus like the Fastrak measures anteriorposterior translation movement (in centimetres), as part of its calculation of position sense error (O'Sullivan et al., 2003), but these translation measurements were found to be small. Similarly, as translation and rotation movements in the low back are small (Bogduk, 1997) any errors recorded, may not have exceeded the error in the testing equipment.
3. Therefore, as the electrogoniometer is easy to use for the participant and researcher, it takes relatively little time to set-up, is accurate and relatively inexpensive, it was felt the benefits of its use outweighed any slight measurement error from cutaneous feedback from the sensor or from "crosstalk".
4. It is acknowledged that other testing apparatus, like an inertial measurement system that can record three dimensional spinal movement in degrees, may also prove to be a useful tool that is low cost, small and portable. It is reported that measurements of low back range in 26 healthy participants were highly correlated

to those recorded by the Fastrak and to those reported in the literature (Tshui-Hung et al., in press). Its use in measuring position sense in future studies should be considered.

Other methodological considerations when measuring position sense

1. In Chapter 3, a comparison of position awareness between participants with and without LBP before and after-work, a sample size of 20 participants with LBP and 20 participants without LBP was calculated to have 90% power to detect a difference in means of 2 degrees error in position sense (Kiefer et al., 1997; Lemeshow et al., 1992). This sample size calculation was based on the data from a previous study investigating position awareness in the low back (Swinkels et al., 2000). The data from the study in Chapter 3, in relation to returning to the "neutral" spinal posture in sitting, was used in the sample size calculation for the studies in Chapters 4 and 5, which investigated position awareness when locating target positions in mid-range in sitting and for locating a "good" sitting posture. This calculation suggested that a sample size of 50 participants was required in each group and was calculated to have 90% power to detect a difference in means equivalent to 2 degrees (Altman, 1991; Kiefer et al., 1997; Lemeshow et al., 1992; Phillips et al., 2005). In retrospect therefore, the study in Chapter 3 was underpowered, specifically in relation to position awareness when returning to the "neutral" spinal posture in sitting.

2. At data collection, ideally the researcher would have been blinded to whether the participant had back pain or not. The recording of the data by the electrogoniometer however, was automated as was the data transfer process into a SPSS database. Subsequently, an independent person coded LBP and NLBP groups, so that the researcher remained "blinded" to participants back pain status during data analysis (see section 3.4.7.2; 4.4.7.2).

3. In Chapter 3 the results suggest that the working day did not impair low back position awareness. The manual workers and sedentary workers however, had travelled from their workplace to the University for testing. It is possible, that work-induced changes in the responses of Golgi tendon organs and muscle spindles (Graham et al., 1986; Hutton et al., 1986; Lagier-Tessonnier et al., 1993), and in the back extensor muscles (Biering-Sørensen, 1984; Mannion et al., 1997a; Roy et al., 1989; Suzuki et al., 1983; Taimela et al., 1999) are likely to have been transient and more easily identified during exposure, or immediately after exposure, to the working envoronment. A study investigating prolonged flexed sitting posture in people without LBP, found impairment of spinal position awareness when they were tested immediately on completing a timed sitting task in a laboratory setting (Dolan et al., 2006). Further studies in the laboratory setting, or on site at the workplace, should investigate whether similar findings would occur in people with and without LBP during or immediately after exposure to sitting or driving at work, or manual work.
4. It is perhaps arbitrary to look at position sense in low back in isolation. Movement is a co-ordinated activity involving multiple joints and muscles. Studies should therefore also investigate position sense in other areas of the body, including the role and proportion of movement and muscle activity occurring at the upper trunk, hips and knees.
5. Testing position sense in isolation may not be the most appropriate strategy. Perhaps it should be tested along with movement sense, postural sway and include measures of muscle activity.

Position of perceived "good" sitting posture to end-range

1. The finding that participants with LBP position their "good" sitting posture closer to end-range extension, may just be a consequence of an overall decrease in their range of low back extension in comparison to people without LBP. To be certain, a study would need to accurately locate and compare the position of end-range extension and flexion, in people with and without LBP.
2. To attribute the decrease in the total sagittal range found in this study in people with LBP, to a decrease in predominately flexion or extension, or both, there needs to be an understanding of where extension and flexion start. Although in this study people with LBP appeared to loose flexion rather than extension range, without confirmation of where extension or flexion starts, this remains unsubstantiated.
3. Some studies have recorded flexion and extension from a participant's initial resting posture. Clinical observations however, suggest this would result in a highly variable starting position, and therefore, very different ranges of flexion and extension seen across individuals with or without LBP. In people without LBP for example, their habitual sitting posture was significantly closer to end-range flexion than the location of their "ideal" sitting posture (O'Sullivan et al., 2010). The terminology used and the interpretation when asking people to locate a particular sitting position could result in a highly variable start position i.e. initial resting posture; their habitual sitting posture; "ideal" sitting posture; their perceived "good" sitting posture. Due to the confusion as to where flexion and extension starts, the total range of sagittal movement was recorded in this study and no attempt was made to quantify the individual ranges of flexion or extension. The relationship of people's "good" sitting posture to their end-range extension was the priority in this study.

8 IMPLICATIONS OF THE RESEARCH

8.1 Importance and originality of the research and what it adds to the body of knowledge

As far as can be determined:

The study in Chapter 2 was the first to investigate the accuracy, stability and through range test-retest reliability of the back electrogoniometer, when compared to measurements using a calibrated, highly accurate, bevel protractor

The study in Chapter 3 was the first to investigate position sense in the low back in a large sample at the beginning and end of a working day.

The study in Chapter 4 was the first to investigate position sense in the low back in sitting, in mid-range random target positions near to the neutral sitting posture, in such a large sample size.

The study in Chapter 5 was the first to investigate where people with LBP believe a “good” sitting posture is located, and its relation to end-range sagittal plane movement in the low back.

The study in Chapter 2 demonstrates the electrogoniometer to be very accurate for through range and stability testing between +/- 60 degrees, with mean errors less than 0.5 degrees when compared to a highly accurate calibrated, bevel protractor. In addition, the simple to use and clinically applicable measuring tool, takes relatively little time to set-up and is relatively inexpensive.

The methodology of measuring position sense in the low back used in this thesis suggests that there is no difference in position sense of the low back between participants with recurrent NSLBP and without LBP. No differences were found before and after work in either sitting or standing, or in sub-group analysis in sedentary workers (Chapter 3). Similarly, no differences were found in mid-range of sagittal plane movement in sitting (Chapter 4), or when returning to a perceived “good” sitting posture (Chapter 5).

The population of people with LBP were primarily those whose episodes of LBP were less than 12 weeks duration. It is possible therefore, that an inability to find greater deficits in position sense in people with LBP was a reflection on the population of LBP participants recruited to these studies. It is important that similar research investigates position sense in people with persistent or recurrent non-specific LBP of greater than 6 weeks duration (NICE, 2009), or who have persistent chronic LBP as defined by European Guidelines as LBP persisting for at least 12 weeks (Airaksinen et al., 2006). It is possible people with persistent recurrent LBP may have had greater errors in position awareness, in comparison to people without LBP.

People with recurrent NSLBP however, did position their "good" sitting posture closer to end-range low back extension. These end-range postures are towards the elastic zone of motion and are where there is increase stress on passive structures (Scannell et al., 2003). This could lead to greater compressive loading of pain-sensitive spinal tissue, as well as increases in facet joint forces and shear forces on discs (Shirazi-Adl et al., 2002) (Chapter 5). These mechanisms may be aetiologic in the recurrence and maintenance of LBP (Paajanen, Erkintalo, Kuusela, Dahlstrom, & Kormano, 1989; Panjabi, 2006; Reeves et al., 2009; Solomonow et al., 1999).

Consequently, measuring "usual" posture and awareness of "good" posture in sitting in relation to the end-range may prove to be a more useful measure, than comparing either postural awareness or range of motion alone. In order to investigate this fully, studies will need to accurately record the end-range flexion and extension positions. To be able to do this, studies at the very least, should consider a participant's initial resting posture (Coates et al., 2001). Ideally they should have certainty as to the true range of flexion and extension, with reference to a recognised, repeatable and measureable start point.

The studies provide researchers with data that can be used as the basis of sample size calculations for future studies investigating position awareness in the low back, including the position of perceived "good" sitting posture in relation to end-range sagittal plane movement.

8.2 Clinical implications

As there is no evidence of sensorimotor changes, when testing the ability to locate target positions, clinical implications are restricted. Testing position sense in the low back, using the method in this thesis of asking patients to reproduce random target positions, would not appear to be a useful clinical tool for investigating potential differences in proprioceptive acuity between people with recurrent NSLBP and without LBP. Adding a trunk muscle fatigue protocol and then asking patients to reproduce random target positions could still be useful, but this needs investigating.

The results however, suggest that for the main results and test-retest data, the error values for people with LBP are consistently slightly greater than those for people without LBP. Future studies using a more specific population of people with LBP, could investigate whether similar tests of position sense result in greater error values been found in people with LBP in comparison to people without LBP.

The results do have some limited use for clinicians as position sense does not appear to be affected by the time of day i.e. between 07.30 and 09.30am and 16.00 and 19.00pm when testing occurred. This is useful knowledge for clinicians as they will not have to see patients at consistent times of the day, when comparing measures of low back position sense.

Questioning patients' understanding of a "good" sitting posture, and observing this position in relation to their end-range of low back extension in sitting, could be a useful assessment tool in the clinic. Educating the patient on a more appropriate "good" sitting posture, could have implications to help minimise LBP during sitting. Education should include how a sitting posture that is near to end-range, could load pain-sensitive spinal tissue and therefore have possible implications for ongoing LBP.

9 AREAS FOR FURTHER RESEARCH

When investigating whether differences in position awareness do exist between people with and without LBP, a number of recommendations could be considered when designing similar studies:

Neurophysiological studies and sensorimotor control

Basic science research could add to the knowledge about the distribution of proprioceptive receptors in the low back, particularly in the muscles of the trunk. A greater understanding of the peripheral and central proprioceptive pathways is also needed. Furthermore, the reflex and cortical afferent and efferent pathways involvement in motor control in both static and dynamic trunk movements need to be better understood. This will help in developing assessment of sensorimotor function and appropriate treatment of any dysfunction found.

In addition, a relationship should be investigated between data on position sense and recordings made by EMG analysis, when it relates to sensorimotor control and movement of the trunk. It would be useful to know whether an accurate measurement of muscle stiffness in the trunk muscles can be established and the possible relationship of this stiffness to sensoriomotor control during static posture and movement of the trunk. There is also still a need for greater understanding of the timing of trunk muscle activation in people with and without LBP.

When designing studies investigating position sense, consideration needs to be given to muscle activity, muscle stiffness and the thixotropic behaviour of muscle, as the immediate history of muscle length and contraction (Proske et al., 1999), alters the response of muscle spindles (Proske et al., 1993) (see sections 1.1.8 and 6.8). Different contraction states (isometric, concentric, eccentric) and length of muscle, prior to locating a target position, could lead to variable degrees of position error and undershoot or overshoot of target angles. This will be influenced by the start position used for testing position sense. Similarly, the rate of muscle spindle discharge may vary depending if the start position was in flexion or extension (Burgess et

al., 1982). Studies have investigated the thixotropic behaviour of muscle and its relationship to position sense in the limbs. There is a need to do similar studies in the muscles of the trunk.

Although cortical function is not fully understood and is intrinsically complex, it does appear that there are changes in brain structure and activity associated with LBP (Wand et al., 2011). Brain imaging appears to show alterations in representation of body parts and movement in the primary sensory and motor cortex in people with pain and this may also occur in people with LBP (Flor et al., 1997; Lotze et al., 2007). Thus, the perception of body position and movement, and the motor responses, can become disrupted. These changes in brain activity may be worthy measures when investigating differences in spinal position awareness and responses to treatment. The location of neuronal activity in the brain can be investigated using fMRI and TMS (Moseley, 2008b; Strutton et al., 2003; Strutton et al., 2005; Tsao et al., 2008a), with EEG informing when it occurs (Moseley, 2008b).

What is also needed is a greater understanding of the contribution of peripheral afferent information and the centrally generated sense of effort, to position and movement sense. Many gaps remain in our understanding of the neurophysiological mechanisms involved in position sense, particularly in the CNS (Proske, 2006). A study involving the fatiguing of the trunk muscles, in an attempt to influence the sense of effort, is warranted. Fatigue would increase the effort that is required to generate a level of muscle force and thus, potentially increase error in position sense (Proske et al., 2009).

Sub-classification of people with LBP

Investigating position sense in a clearly defined population of people with LBP could be useful. Participants could be recruited based on the length of time of their duration of LBP (acute, sub-acute or chronic), or whether recurrent / persistent LBP. There remain however, difficulties and inconsistencies in the literature as to the definitions and terminology used to identify these populations (Airaksinen et al., 2006; NICE, 2009; Stanton et al., 2010).

Investigating position sense in people with LBP within sub-groups, based on known pathologies, could be useful. The diagnoses could be based on the location of LBP, pathological processes e.g. OA, disc injury, or post-operative procedures e.g. discectomy, fusion. There are however, difficulties in accurate diagnosis, different stages of disease processes and people without LBP may exhibit similar pathological changes (Buirski & Silberstein, 1993; Magora & Schwartz, 1976; Paajanen et al., 1989; Wiesel, Tsourmas, Feffer, Citrin, & Patronas, 1984). In addition, there is a lack of sensitivity and specificity in clinical tests and difficulties with nomenclature. Large variability of results within each sub-group is likely to occur making it difficult to identify meaningful differences in position awareness, between people with and without LBP.

Investigating position sense in people with LBP within sub-groups, based on a classification system that defines people into an active extension pattern and an active flexion pattern (O'Sullivan, 2005; Sheeran et al., 2012), could be useful. It is reported that people with chronic LBP classified into an extension pattern and those with a flexion pattern, reposition differently to each other, when attempting to relocate to a therapists identified neutral sitting posture (Sheeran et al., 2012).

Disability and pain

Future studies could set an entry criterion with a minimum score for disability of 4 points for RDQ on the day of testing. This minimum value is recommended for participants entering clinical trials to enable meaningful improvements following intervention to be detected (Stratford et al., 1996). Participants would therefore be more representative of patient populations used in clinical intervention studies, making the results more relevant for researchers and clinicians. A greater understanding of the consistency of the levels of disability and pain in participants over preceding weeks would also be useful.

The influence of fear of movement, fear of pain and (re)injury (Vlaeyen et al., 1999; Watson et al., 1997a) and mental stressors (Flor et al.,

1985) on trunk muscle function during movement (Figure 6:1), and its relation to position sense, needs investigating. If fear and mental stressors alter trunk muscle function, this could change the sensory feedback informing position sense or the motor output response. This could potentially lead to alterations in acuity of low back position awareness in people with LBP, or in people without LBP who have similar fears.

Measuring position sense

Measuring position sense in the low back in people with and without LBP, with different measuring devices at the same time, would help to establish whether a “gold standard” measure of position awareness in the low back is available. A person with or without LBP who has a high error score for position awareness, would be expected to have a similar high value for their error score when completing the established measure. Only then can there be certainty of the concurrent validity (Streiner et al., 2008), of measuring devices used to measure position awareness in people with and without LBP.

There is a need to have numerous experiments over time, before sufficient evidence of the validity of a measure exists. In addition, a reliability coefficient only refers to a specific population (Streiner et al., 2008). Consequently, the same population will need to be tested in numerous experiments, including repeating test-retest reliability, to gain greater insight into the reliability and validity of a measure.

Once baseline data are collected on sagittal plane movements, further work could be undertaken to determine the involvement of other planes of low back movement in position sense. These could be measured individually or collectively with all spinal movements, if issues around “crosstalk” could be addressed.

For a more thorough assessment of proprioceptive acuity in the low back, it needs to include assessments of both position and movement sense.

As speed and motion characteristics of the back during position sense testing may be different between people with and without LBP, similar studies investigating speed and control when testing acuity of position sense are warranted. Any delayed awareness of low back posture and movement during functional tasks in people with LBP, could result in a slow response to normal or abnormal loading, thereby making the back vulnerable to injury and pain. It would also be useful to investigate speed and motion characteristics following prolonged common everyday functional tasks that may have resulted in a reduction in the efficiency of trunk muscles that provide information on position sense.

In addition, studies have suggested there are separate central processing mechanisms for afferent information on position and movement sense (Brown et al., 2003; Kurtzer et al., 2005; Proske, 2006). Future studies investigating speed and motion characteristics during functional tasks should attempt to measure both, by recording distance moved, direction, and any drift in start and target positions of the trunk when assessing position sense in people with and without LBP. In addition, measuring the perception of movement as a test of kinaesthesia should be considered (Lee et al., 2010; Silfies et al., 2007; Taimela et al., 1999).

Similarly, the control of spinal movement could also be investigated during dynamic tasks such as sit to stand, squatting and bending. In addition, consideration should also be given to the role and proportion of movement and muscle activity occurring at the upper trunk, hips and knees. Movement is a co-ordinated activity involving multiple joints and muscles. Investigating for example, the role of the gluteal muscles, their interaction with activity of muscles of the trunk and how this relates to low back position sense, would be an important addition of knowledge. Studies should also investigate position sense in other areas of the body such as the hip in people with and without LBP.

Measuring position sense at the end of an extended period of prolonged slump sitting e.g. timed periods upto the length of a working day, is worthy of investigation. This end-range position can result in abnormal

loading, potential injury and pain (Panjabi, 2006). Animal studies have suggested that activity of multifidus can take over 7 hours to recover following just 20 minutes of static or repetitive lumbar flexion loading to the cat spine (Jackson et al., 2001; Solomonow et al., 2003). Investigating the effect on multifidus activity, and its recovery, following exposure to prolonged slump sitting in people with and without LBP, should be considered. Due to the high density of muscle spindles found in the deep trunk muscles (Amonoo-Kuofi, 1983), any alterations in muscle activity could effect the afferent proprioceptive information and impair position sense. Studies have found that prolonged slumped sitting impairs spinal position awareness in people without LBP (Dolan et al., 2006), but the effect is unknown in people with LBP.

Perhaps measuring position sense in the low back after a fatiguing protocol for the low back may have revealed differences in position sense between people with and without LBP. Muscle fatigue has been shown to alter control of standing posture by a loss of muscle output, affecting proprioceptive feedback (Vuillerme, Danion, Forestier, & Nougier, 2002; Wilson, Madigan, Davidson, & Nussbaum, 2006). Changes to sensory feedback from muscle spindles in fatigued muscles, alters the central motor commands that control posture. People with LBP and fatigue of the deep trunk muscles, would become more reliant on sensory feedback from the muscles of the ankle for postural control. As a consequence, they have increased postural sway, due to a lack of postural readjustments been made at multi-segmental levels by the deep trunk muscles (Brumagne et al., 2008). Investigating position sense and postural sway in sitting and standing, following a fatiguing protocol to the trunk muscles, would further help the understanding in this area.

The term muscle fatigue (Gandevia, 2001; Selen et al., 2007), implies exhaustion and scientifically is measured as a decline in muscle force with repeated activity (Proske, 2005). Although carried out on the elbow, a study found that eccentric exercise in the arm that led to an

average decrease in muscle force of 46%, resulted in significant position matching errors (Walsh et al., 2004). Future studies investigating if trunk muscle fatigue leads to any differences in low back position sense between people with and without LBP, will need to consider how to simply, effectively and safely induce trunk muscle fatigue (possibly in relation to work activities) within the experimental setting.

Investigating position sense in isolation may have limited value. The combined investigation of postural responses in the trunk and proprioceptive control in people with and without LBP might be more useful. Studies looking at coherent linking of position sense, muscle activation and postural control strategies are needed. These should involve large numbers of people, of different ages, with and without LBP, different levels of disability and with varying beliefs about back pain and movement. This may help identify sub-groups of people with a proprioceptive deficit in position or movement sense, or postural sway.

If any deficits were identified they may be due to a reduction in the efficiency of the trunk muscles following prolonged activity, or alterations in activation and recruitment of trunk muscles in response to pain or expectation of pain. Appropriate rehabilitation could then be designed to target any specific or generalised deficit in proprioception, in an attempt to decrease disability and pain in people with LBP.

Preliminary information from participants with NLBP suggest spinal position sense can be accurate following brief postural education (Dolan et al., 2006). In addition, although carried out on healthy individuals and in the upper limb, it is reported that only 10-minutes of training involving active use of the muscles, can improve upper limb position sense that lasts until re-testing 24 hours later. The improvement in position sense is dependent on active movement, as it doesn't occur when the same movements are done passively. This suggests motor learning has a central role in plasticity of the sensorimotor system (Ostry et al., 2010).

Studies on proprioception, whether investigating position or movement sense, or postural control, commonly have small numbers of participants (Descarreaux et al., 2005; O'Sullivan et al., 2003). They also often investigate young age groups (Brumagne et al., 2008; Dolan et al., 2006; Janssens et al., 2010) and rarely comment on their power (Brumagne et al., 2000; Descarreaux et al., 2005; Gill et al., 1998; Lee et al., 2010; O'Sullivan et al., 2003; Taimela et al., 1999). A similar study to Chapter 3, looking at sub-groups from occupations should be considered, but with sufficient numbers of participants. In an attempt to maximise recruitment all methods of recruitment should be utilised and funded, including regular newspaper advertisements.

Position of perceived "good" sitting posture to end-range

Based on the findings of the research in this thesis, a particular area of interest for further investigation is the relationship of perceived "good" sitting posture and end-range of low back extension, and the possible implication for ongoing or recurrent episodes of LBP. What is unknown is whether there is a specific point towards end-range extension that will result in increase loading of pain-sensitive spinal tissue and LBP. Biomechanical modelling however, has shown that flattening of an excessive lumbar lordosis by 16 to 20 degrees to a more neutral posture, significantly decreases: muscle forces (50N/m to 1N/m); facet joint forces; and shear forces on discs (Shirazi-Adl et al., 2002).

In people with LBP, the position of their "good" sitting posture closer to end range extension, appears to be a postural control strategy resulting in bracing of the low back in an attempt to limit movement and gain postural stability. This may be influenced by the belief that a very erect, extended low back with a marked and rigid lumbar lordosis (or thoraco / lumbar lordosis), is an appropriate postural strategy in sitting. This possibly reflects a lack of variability in postural control without the necessary, multi-segmental adjustments seen in people without LBP. Studies using measures of postural stability and control, along with EMG and brain imaging are needed to investigate this. Similarly, a study investigating people's "usual" posture in sitting and its implications for end-range loading and LBP is needed.

10 SUMMARY OF FINDINGS

The studies in this thesis found;

- The electrogoniometer is a valid and reliable measure of angles between -60 to 0 to +60 degrees of movement, when compared to the measurements of a very accurately calibrated, bevel protractor (Chapter 2).
- No differences in the accuracy of low back position awareness between people with recurrent NSLBP and without LBP, in sitting or standing, either before or after-work (Chapter 3).
- Reposition errors were greatest when people (with recurrent NSLBP and without LBP) were returning to a neutral sitting posture (Chapter 3).
- Larger reposition errors were evident in people with recurrent NSLBP when returning to the neutral sitting posture when compared to people without LBP before-work, although these differences were small and non-significant (Chapter 3).
- Sedentary occupation had no effect on low back position acuity, either before or after-work. Unfortunately, uncertainty exists about the effect of occupation on position sense in manual workers and drivers, as the sample sizes in these occupations were too small.
- There were no differences in the accuracy of low back position awareness in mid-range of low back sagittal plane movement in sitting or when returning to a “good” sitting posture between people with recurrent NSLBP and without LBP (Chapters 4 and 5).
- People with recurrent NSLBP positioned their “good” sitting posture significantly closer to end-range of low back extension than people without LBP (Chapter 5).
- People with recurrent NSLBP had significantly less total range of low back sagittal plane movement than people without LBP (Chapter 5).

11 CONCLUSION

The studies in this thesis found no differences in the accuracy of low back position awareness between participants with recurrent NSLBP and without LBP (Chapters 3 to 5). A person's sedentary occupation also had no effect on position acuity in the low back. Uncertainty exists however, about the effect of manual and driving occupations on position sense, as sample size in these groups were too small (Chapter 3). In this study, the largest reposition errors were on returning to a neutral sitting posture, with a trend suggesting this may be greater in people with LBP.

Isolated testing of low back position sense, by asking people to reproduce random target positions, does not appear to be a useful assessment tool to investigate for differences in proprioceptive acuity between people with and without LBP, at least in the type of population used in this thesis.

The position of perceived "good" sitting posture, was significantly closer to end-range low back extension in people with LBP than in people without LBP (Chapter 5). Observing where patients believe their "good" sitting posture is located, and its relationship to their end range of low back extension in sitting, could be a useful assessment tool in the clinic. Encouraging a more appropriate "good" sitting posture that is less likely to load pain-sensitive spinal tissue, could have implications to help minimise LBP during sitting.

Studies are needed to investigate the coherent linking of position sense, movement sense, trunk muscle activation, a reduction in the efficiency of the trunk muscles after prolonged activity, trunk muscle fatigue, postural control strategies and position of low back posture in relation to end of range. In addition, this research should also investigate brain activity during proprioceptive testing and in static and dynamic functional tasks, in people with different levels of disability and, varying beliefs and fears about back pain and movement.

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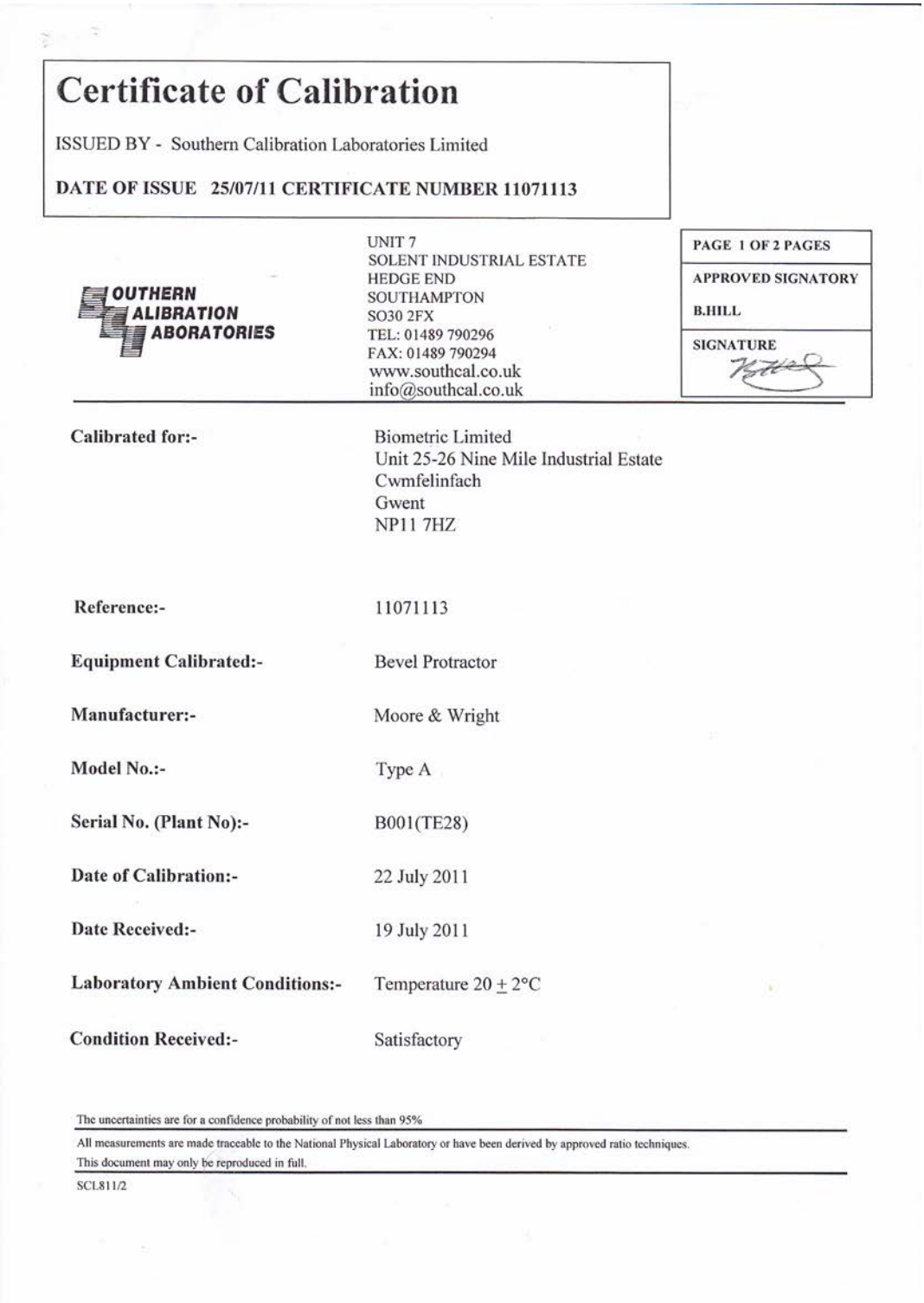
13 APPENDICES



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Laboratory Ambient Conditions:-	Temperature 20 ± 2°C
Condition Received:-	Satisfactory

The uncertainties are for a confidence probability of not less than 95%

All measurements are made traceable to the National Physical Laboratory or have been derived by approved ratio techniques.

SCL811/2

Appendix 2:1. Certificate of Calibration (p1 of 2)

Certificate of Calibration

Southern Calibration Laboratories Limited

CERTIFICATE NUMBER 11071113 PAGE 2 OF 2 PAGES

BASIS OF CALIBRATION:- To the requirements of BS1685:2008
Bevel Protractors (Mechanical and Optical)

METHOD OF CALIBRATION:- Using methods of metrology derived from First Principles the instrument has been examined for:

a) lateral squareness of blade side to protractor body
b) straightness of blade
c) flatness of blade
d) parallelism of blade
e) straightness of stock
f) angles of blade ends
g) accuracy of graduations

RESULTS:-

a) Lateral squareness of blade side to protractor body was determined to be within 0.020mm per 25mm for both blades.
b) The straightness of the 6" blade was found to be within 0.002mm and that of the 12" blade 0.003mm.
c) Flatness of the 6" blade was determined to be within 0.022mm and for the 12" blade within 0.063mm.
d) The parallelism of the 6" blade was within 0.003mm over its length and that of the 12" blade 0.005mm over its length.
e) Straightness of the stock of the instrument does not exceed 0.007mm
f) The angles subtended by the blade ends for the 6" blade were determined to be 45° 00' and 60° 00' and for the 12" blade 45° 01' and 59° 59'
g) The accuracy of the graduations of the angular scale were determined to be within 5 minutes of arc for any position of the graduated circle.

UNCERTAINTY OF MEASUREMENT ± 1 minute of arc (angular)
± 0.003mm (linear)

	Asset Number	Calibration Due
Equipment Used	627M	Nov 2011
	260M	Sept 2011
	741M	Dec2012
	1113M	Nov 2015
	266M	Nov 2012
	283M	Aug 2011

The uncertainties are for a confidence probability of not less than 95%

SCL812/1

SOUTHAMPTON & SOUTH WEST HANTS
JOINT LOCAL RESEARCH ETHICS COMMITTEE

Chairman: Dr A Kermode

Administrator: Mrs Clair Wright
Trust Management Offices
Mailpoint 18
Southampton General Hospital
Tremona Road
Southampton
Hants
SO16 6YD

Tel: (023) 8079 4912
FAX: (023) 8079 8678

Ref CPW

6 March 2001

Mr D Phillips
School of Health Professions & Rehabilitation Sciences
University of Southampton
Highfield
Southampton

Dear Mr Phillips

RE: 056/01 - Spinal proprioceptive acuity in subjects with and without chronic low back pain in sedentary, driving and manual occupations.

The Joint Ethics Committee considered your application for the above study at its recent meeting and I am pleased to inform you that **approval was given** provided that the sentence "you may be paid a fee" is replaced with something along the lines " reimbursement for you travel/time is available".

May I draw your attention to the enclosed conditions of approval which **must be complied with. In particular: it is mandatory that ALL correspondence, information sheets, consent forms, adverts etc, carry the LREC submission number.** YOU SHOULD BE AWARE THAT A SUBSTANTIAL RANDOM PROPORTION OF RESEARCH PROJECTS ARE AUDITED ANNUALLY.

The data protection officer for the Trust/University is to be notified of the project.

This committee is compliant with the International Committee on Harmonisation/Good Clinical Practice (ICH) Guidelines for the Conduct of Trials involving the participation of human subjects as they relate to the responsibilities, composition, function, operations and records of an Independent Ethics Committee/Independent Review Board. To this end it undertakes to adhere as far as is consistent with its Constitution, to the relevant clauses of the ICH Harmonised Tripartite Guideline for Good Clinical Practice, adopted by the Commission of the European Union on 17 January 1997.

The composition of the committee is enclosed for your files and confirms which members were present at the meeting. Most pharmaceutical companies request this information and we would be grateful if you could forward this to them if appropriate.

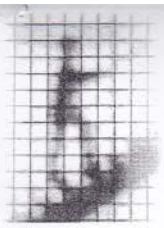
Should any unforeseen problem of either an ethical or procedural nature arise during the course of this research and you feel the Joint Ethics Committee may be of assistance, please do not hesitate to contact us.

Yours sincerely,

CMOright

Clair Wright
Administrator

Appendix 3:1. Ethics approval letter



Health and Rehabilitation Research Unit

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WWW http://www.sohp.soton.ac.uk/sohp/

7th May 2003

Version 4

Insert address

Dear *insert name*

Re: Spinal Proprioceptive Acuity In Subjects With And Without Chronic Low Back Pain In Sedentary, Driving And Manual Occupations (Positional Awareness of the Spine)

I am a Lecturer in Physiotherapy at the University of Southampton undertaking a 2-year research project, which started in September 2001, aimed at assessing the low back in workers who *rarely/never* or *occasionally/regularly* get low back pain. One of the occupational groups I plan to look at is.....*(insert either sedentary, driving, manual)* workers. In an attempt to recruit potential volunteers for the study from your workplace, please would you consider informing your employees of the study, by distributing the .....*(insert either research information and/or poster and/or advert* (see attached). Volunteers would be required on 2 occasions (45 minutes before work and 30 minutes after work, respectively) at the University or at the work place if preferred. Reimbursement for travel/time is available if required. The study has received ethical approval from the Southampton & South West Hants Local Research Ethics Committee - Submission No. 056/01 and funding from the Arthritis Research Campaign.

As you may be aware back pain is one of the costliest medical conditions in the UK and has been reported to affect 40% of the population in any one-year. Potentially this is an area where innovative research may lead to improvements in the assessment and ultimately treatment of low back pain.

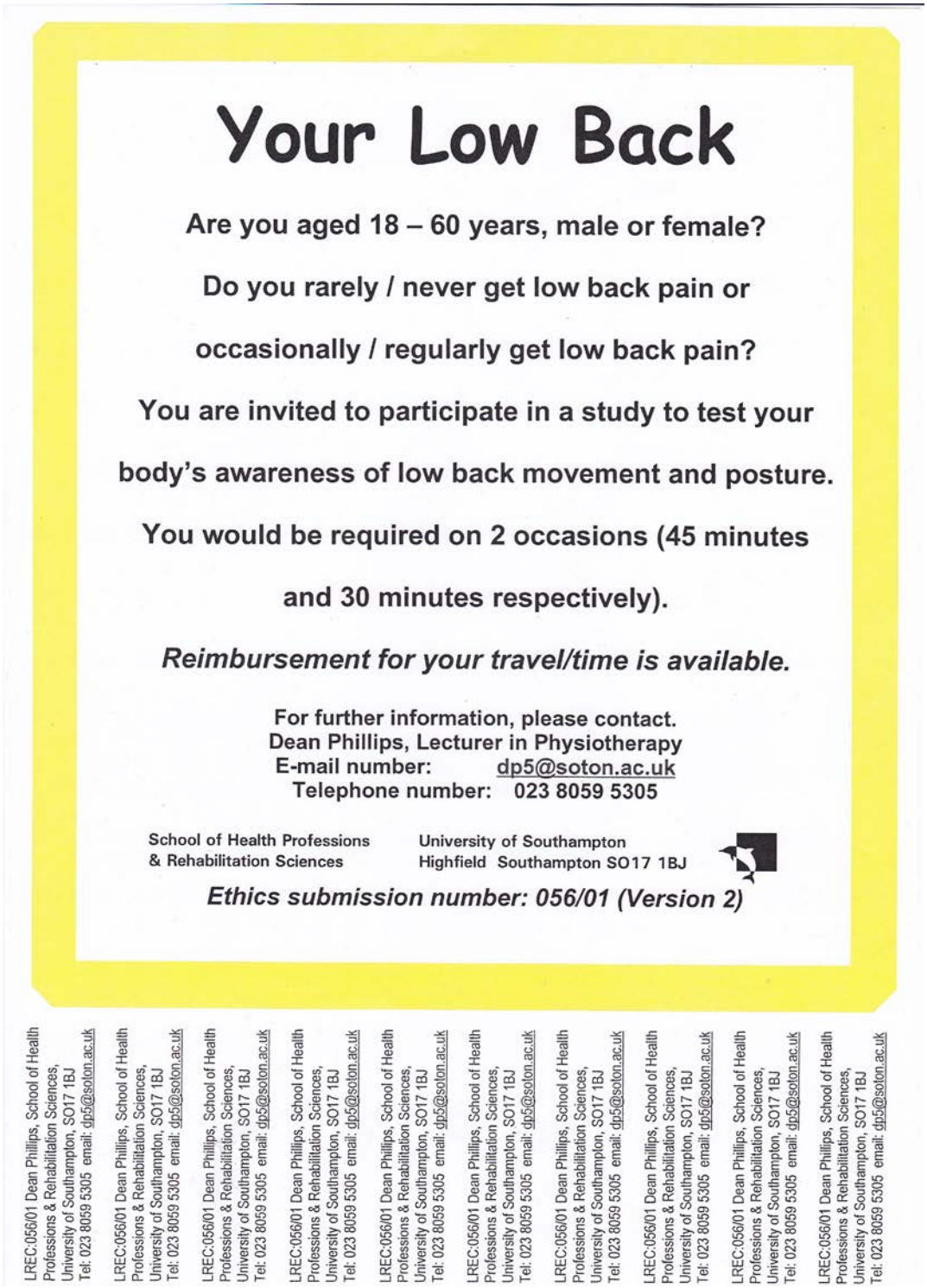
If you have any specific queries please contact me on Tel: 023 8059 5305; Fax: 023 8059 5301; Email: dp5@soton.ac.uk

Thank you for taking the time to read this. Even if you agree to assist at this stage you are free to withdraw this agreement at any time without giving reason.

Yours sincerely

Dean Phillips
Lecturer in Physiotherapy

Appendix 3:2. Recruitment letter



Appendix 3:3. Recruitment poster for people with and without LBP

Health and Rehabilitation Research Unit

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Appendix 2

7th October 2002
Version 1

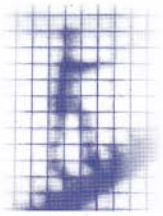
Volunteers Required for Low Back Research Study

Are you aged 18 – 60 years, male or female? Do you drive or do physical/manual work for the majority of your working day? Do you rarely/never get low back pain or occasionally/regularly get low back pain? You are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between non-low back pain and low back pain sufferers. This information may help in the future assessment and treatment of low back pain. You would be tested on 2 occasions (45 minutes and 30 minutes respectively). Reimbursement for your travel/time is available if required. The Arthritis Research Campaign is funding the research. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton, Highfield, Southampton SO17 1BJ Tel: 023 8059 5305
e-mail: dp5@soton.ac.uk Ethics submission number: 056/01 (version 1: 7.10.02)

University of Southampton

arc 0870 850 5000 www.arc.org.uk
Committed to curing arthritis

Appendix 3:4. Newspaper advert



Health and Rehabilitation Research Unit

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TAKING PART IN RESEARCH – General Information

Date: 7.10.02
Version: 4

Local Research Ethics Committee Submission No: 056/01

Study Title: **Spinal Proprioceptive Acuity In Subjects With And Without Chronic Low Back Pain In Sedentary, Driving And Manual Occupations (Positional Awareness of the Spine)**

You are being invited to take part in the above research project. Here is some information to help you decide whether or not to take part. Please take time to read the following information carefully and discuss it with friends and relatives. Please ask me if there is anything you do not understand or if you would like more information. Take time (at least 1-week) to decide whether or not you wish to take part. Thank you for reading this.

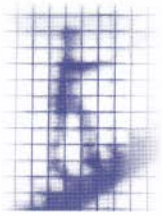
1. You will not receive any direct benefit from taking part in the study. However, information obtained during the course of the study may help us to understand better about low back pain (LBP). It may also help us in selecting treatment for future patients.
2. It is up to you to decide whether to take part or not. If you do decide to take part you will be asked to sign a consent form. Even if you do sign a consent form, you will be free to withdraw from the study at any time without giving a reason.
3. Reimbursement for your travel/time is available.
4. All the information collected about you during the course of the research will be kept strictly confidential. Any published report of the research will not identify you.
5. Your GP is not being informed about this project as there is no treatment intervention as part of the study.
6. Consumers for Ethics in Research (CERES) publish a leaflet entitled 'Medical Research and You'. This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES, PO Box 1365, London N16 0BW.

Attached is information related to the specific research project.

Yours sincerely

Dean Phillips
Lecturer in Physiotherapy

Appendix 3:5. Information sheet (p1 of 3)



Health and Rehabilitation Research Unit

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WWW http://www.sohp.soton.ac.uk/sohp/

INFORMATION FOR SUBJECTS ABOUT THE STUDY

Date: 7.10.02
Version: 4
Local Research Ethics Committee Submission No: 056/01

Study Title: **Spinal Proprioceptive Acuity In Subjects With And Without Chronic Low Back Pain In Sedentary, Driving And Manual Occupations (Positional Awareness of the Spine)**

What is the purpose of the study?
The purpose of the study is to test the positional awareness of the spine in low back pain (LBP) and non-low back pain (NLBP) workers from sedentary, driving and manual occupations. The study is hoping to identify whether there is a relationship between alterations in spinal awareness and the presence or not of LBP. It is hoped that a future study will look at whether the teaching of spinal awareness exercises can improve LBP.

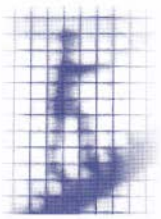
Why have I been chosen?
You have been chosen because you belong to one of the specific occupational groups above. In total 20 NLBP and 20 LBP subjects from each occupational group will be involved in the study.

Who is organising the study?
I am organising the study as part of my commitment to research at the University of Southampton. The research is being funded by the Arthritis Research Campaign and will be completed in 2 years.

What will happen to me if I take part?
If you volunteer for the study you will be required to take part for 45 minutes prior to the start of a working day and 30 minutes at the end of a working day. You will need to wear shorts and your mid to low back will need to be visible. A commonly used flexible measuring device will be attached to your spine with a second one attached over the outside of your thigh/hip region (one side only). They will be attached with self-adhesive tape. You will then be required to perform some forward and backward movements of your spine while in standing and sitting. The measuring device will then take measurements of your spine, which will be recorded on a computer. During each session a flexible measuring device will also be attached to the outside of one elbow. You will be asked to bend and straighten your elbow while measurements are recorded on the computer. This elbow test is necessary to give base line information on your positional awareness in other regions of your body. During each test procedure, you will be required to wear a blindfold which you can remove yourself at any time should you feel the need to. The blindfold allows for a more specific test of positional awareness rather than relying on sight to aid this awareness. At both sessions you will also be asked to fill in 2 short questionnaires.

A smaller number of subjects will be asked to participate in a reliability study, to ensure the accuracy of the measurement equipment. These participants would be tested for a further 30-minute session 1-week after the initial assessment and a final 30-minute session 2 weeks after the initial assessment. These measures will be taken at the end of your working day.

All measurements can be taken at your workplace or at the University of Southampton, whichever is the most convenient to you. If you choose to be tested at the University reasonable travel expenses may be paid. You may also be offered a reasonable reimbursement to offset any possible loss of income incurred while being tested as part of the study.



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INFORMATION FOR SUBJECTS ABOUT THE STUDY cont/d page 2 of 2

Date: 7.10.02
Version: 4
Local Research Ethics Committee Submission No: 056/01

Study Title: **Spinal Proprioceptive Acuity In Subjects With And Without Chronic Low Back Pain In Sedentary, Driving And Manual Occupations (Positional Awareness of the Spine)**

Are there any disadvantages in taking part in this study?
An allergy to the adhesive tape used to attach the spinal electro-goniometer is unlikely, but possible and would lead to a local temporary skin reaction. As a precaution, on removal of the adhesive tape your skin will need to be washed local to the tape application. If you have a known allergy to tape you will be unable to participate in the study. You should experience no pain during testing as the movements that you perform should be within your own available pain free spinal range. In the unlikely event that you experience any side effects you will need to stop immediately and inform the researcher. If you experience any side effects after testing please contact the researcher on telephone: 023 8059 5305.

What are the possible benefits of taking part?
The information obtained from this study may help us to treat future patients with LBP better. There will be no direct clinical benefit from taking part in this study.

What if something goes wrong?
I wouldn't expect anything to go wrong in view of the minimal assessment that is involved in the study and because you are not a patient receiving treatment. In the unlikely event, the University of Southampton provide insurance cover for this study. Should you wish to complain about the study please contact Professor Rosemary Barnitt, Head of School of Health Professions & Rehabilitation Sciences (see letterhead for contact details).

Confidentiality – who will know I am taking part in the study?
All information which is collected about you during the course of the research, will be kept strictly confidential. Information will be anonymised so that you cannot be recognised from it.

GP Notification
As there is no treatment intervention your GP will not be informed about your involvement in the study.

LREC Approval
The Southampton & South West Hants Local Research Ethics Committee has approved the study Submission Number 056/01

What will happen to the results of the study?
Please let me know if you wish to be posted a copy of the published results at the end of the study.

Contact for further information
For further information please contact me on Tel: 023 8059 5305. Should you wish to speak to an independent person about the study please contact Professor Rosemary Barnitt, Head of School of Health Professions & Rehabilitation Sciences (see letterhead for contact details).

Thank you for reading this information. Please let me know if you decide to participate in the study by completing the tear off slip on the cover letter and returning it to me in the S.A.E. provided. You will then be required to sign a consent form prior to testing.

Yours sincerely

Dean Phillips
Lecturer in Physiotherapy

Pre-test Screening Questions

Box section to be completed by researcher	Subject number: _____
sitt 1st st 1st	LBP NLBP S M D

Thank you for volunteering to take part in the study. Prior to testing I need to ask you some general medical questions to ensure your suitability for the study. If you answer yes to questions 1-4, please give details in the space below, recording the question number for reference.

Yes	No	
☐	☐	1. Is your general health good – any operations or major illnesses?
☐	☐	2. Any history of Menniere's disease, vertigo, vestibular disturbances that may affect balance?
☐	☐	3. Are you on any medication at the present time?
☐	☐	4. Have you ever taken steroid or blood thinning tablets (anticoags). If yes, when & for how long.
☐	☐	5. Have you had low back pain (LBP) in the last 3 months that has lasted 24 hrs or more.
☐	☐	6. In the past have you received medical advice related to your back pain on at least one occasion?

_____
_____
_____
_____
_____

Body chart (complete over page):

History of LBP (original onset to present day and any treatment):
How many years

Episodes of LBP per year:_____ average duration of each episode (days):_____

Time off work (in days or hrs) due to LBP in last month___; in last year_____ When?____

On average how many hours per working day do you: SIT___ DRIVE ____ DO MANUAL WORK ___

What is your dominant arm: LEFT RIGHT

Any neck or arm pain. If so, which side: _____

Any right hip pain: YES NO

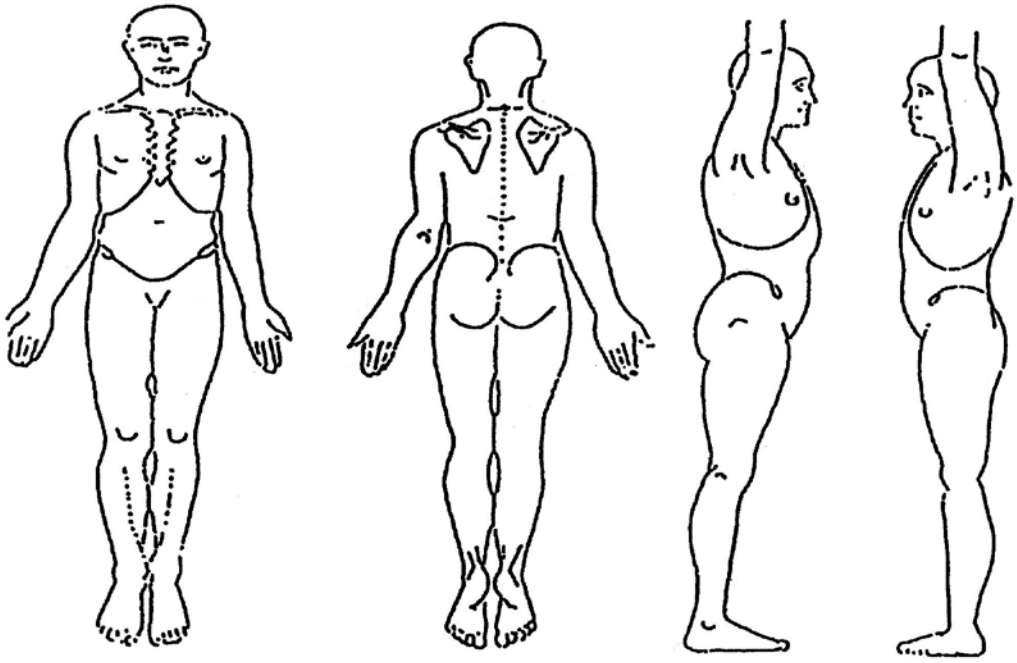
DOB:_____

Height:_____ Weight:_____

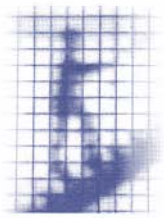
Appendix 3:6. Confirmation of eligibility (p1 of 2)

Subject number: _____

Body Chart



Further information detailed for any questions (note question number)



Health and Rehabilitation Research Unit

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WWW http://www.sohp.soton.ac.uk/sohp/

Consent Form

Study Number: 056/01

Patient Information Number for this trial: Date 07.10.02 / Version 4

Title of Project: Spinal Proprioceptive Acuity In Subjects With And Without Chronic Low Back Pain (Positional Awareness of the Spine)

Name of Researcher: Dean Phillips

Name and number of independent person: Professor Rosemary Barnitt; Tel: 023 8059 2142
Head of School of Health Professions & Rehabilitation Sciences, University of Southampton.

Please initial box

1. I confirm that I have read and understand the information sheet dated 07.10.02 ..... (version 4) for the above study ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without my medical care or legal rights being affected. ☐
3. I have no known allergy to adhesive tape ☐
4. I agree to take part in the above study. ☐
5. I also agree to take part in the reliability testing for the above study, if required. ☐

Name of patient	Date	Signature
Researcher	Date	Signature

1 for patient; 1 for researcher

Appendix 3:7. Consent form

The Modified Roland Questionnaire **subject:_____ AM PM**

Today, prior to testing how many hours did you: SIT____ DRIVE _____ DO MANUAL WORK ____

When your back or leg hurts, you may find it difficult to do some of the things you normally do. This list contains some sentences that people have used to describe themselves when they have back pain or sciatica.

When you read them, you may find that some stand out because they describe you ***today***. As you read the list, think of yourself ***today***. When you read a sentence that describes you today, put a check in the yes column. If the sentence does not describe you today, check the no column.

Yes	No	
☐	☐	1. I stay at home most of the time because of my back problem or leg pain (sciatica).
☐	☐	2. I change position frequently to try and get my back or leg comfortable.
☐	☐	3. I walk more slowly than usual because of my back problem or leg pain (sciatica).
☐	☐	4. Because of my back problem I am not doing any jobs that I usually do around the house.
☐	☐	5. Because of my back problem, I use a handrail to get upstairs.
☐	☐	6. Because of my back problem, I have to hold on to something to get out of an easy chair.
☐	☐	7. I get dressed more slowly than usual because of my back problem or leg pain.
☐	☐	8. I only stand for short periods of time because of my back problem or leg pain.
☐	☐	9. Because of my back problem, I try not to bend or kneel down.
☐	☐	10. I find it difficult to get out of a chair because of my back problem or leg pain (sciatica).
☐	☐	11. My back or leg is painful almost all of the time.
☐	☐	12. I find it difficult to turn over in bed because of my back problem or leg pain.
☐	☐	13. I have trouble putting on my socks (stockings) because of the pain in my back or leg.
☐	☐	14. I only walk short distances because of my back or leg pain (sciatica).
☐	☐	15. I sleep less well because of my back problem.
☐	☐	16. I avoid heavy jobs around the house because of my back problem.
☐	☐	17. Because of my back problem, I am more irritable and bad tempered with people than usual.
☐	☐	18. Because of my back problem, I go upstairs more slowly than usual.
☐	☐	19. I stay in bed most of the time because of my back or leg pain (sciatica).
☐	☐	20. Because of my back problem, my sexual activity is decreased.
☐	☐	21. I keep rubbing or holding areas of my body that hurt or are uncomfortable.
☐	☐	22. Because of my back problem, I am doing less of the daily work around the house than I would usually do.
☐	☐	23. I often express concern to other people over what might be happening to my health.

Please return this completed questionnaire to Dean Phillips, in person, or in the prepaid envelope supplied. Thank you for your co-operation.

Appendix 3:8. Modified Roland Disability Questionnaire

Short-form McGill Pain Questionnaire (Ronald Melzack)

Box section to be completed by researcher

Subject number: _____

AM PM LBP NLBP S M D

Does each word describe the pain you are experiencing **NOW** at this point in time. Please rate the intensity of each particular quality of pain. Please √ the appropriate box

	NONE	MILD	MODERATE	SEVERE
THROBBING				
SHOOTING				
STABBING				
SHARP				
CRAMPING				
GNAWING				
HOT-BURNING				
ACHING				
HEAVY				
TENDER				
SPLITTING				
TIRING-EXAUSTING				
SICKENING				
FEARFUL				
PUNISHING-CRUEL				

Place a **vertical line** on the line below at the point where you would score your low back pain

i) NOW

No pain _____ Worst possible pain

ii) AVERAGE

No pain _____ Worst possible pain

iii) AT IT'S WORST

No pain _____ Worst possible pain

Present Pain NOW at this point in time (please √)

0 NO PAIN _____
1 MILD _____
2 DISCOMFORTING _____
3 DISTRESSING _____
4 HORRIBLE _____
5 EXCRUCIATING _____

Appendix 3:9. Short-Form McGill Pain Questionnaire

		LBP *n=26*	NLBP *n=30*
Age in years	Mean (SD) Median (range)	43.5 (8.9) 45.5 (23, 57)	43.2 (8.9) 41.5 (29, 60)
Male / female		7/19	8/22
Weight in kg	Mean (SD) Median (range)	72.7 (16.9) 69 (49, 111)	65.9 (12.6) 65 (50, 104)
Height in cm	Mean (SD) Median (range)	171.8 (9.2) 170 (160, 197)	170.2 (10) 169.5 (155, 197)
Body mass index (BMI)	Mean (SD) Median (range)	23.75 (3) 23.4 (19.7, 31.3)	24.1 (4) 23.9 (15.5, 33.5)
Years since onset of LBP	Mean (SD) Median (range)	10.2 (8.8) 7 (0.58, 31)	
Duration of LBP episodes in days	Mean (SD) Median (range)	18.2 (33.8) 2.5 (1, 105)	

Footnote: For years since onset of LBP, 3 participants were unable to specify (n=23)**.** For average duration of LBP episodes, 9 participants were unable to specify (n=17)

Appendix 3:10a. Participant characteristics sedentary workers

		LBP *n=22*	NLBP *n=7*
Age in years	Mean (SD) Median (range)	43.6 (11.9) 45 (19, 60)	38.7 (10.2) 38 (22, 54)
Male / female		10/12	2/5
Weight in kg	Mean (SD) Median (range)	74.4 (12.4) 75.5 (51, 98)	70.5 (17.2) 65 (53, 106)
Height in cm	Mean (SD) Median (range)	169.8 (10.4) 168.5 (152, 192)	170.1 (9.4) 170 (161, 190)
Body mass index (BMI)	Mean (SD) Median (range)	25.3 (3.9) 24.8 (17, 34.6)	23.9 (3.8) 23.3 (18.7, 28.6)
Years since onset of LBP	Mean (SD) Median (range)	12.1 (12.8) 6 (1, 40)	
Duration of LBP episodes in days	Mean (SD) Median (range)	7.3 (16.7) 2 (1, 75)	

Footnote: For average duration of LBP episodes, 2 participants were unable to specify (n=20)

Appendix 3:10b. Participant characteristics manual workers

		LBP *n=13*	NLBP *n=3*
Age in years	Mean (SD) Median (range)	46.2 (7.8) 45 (33, 56)	36.33 (5.9) 34 (32, 43)
Male / female		10/3	3/0
Weight in kg	Mean (SD) Median (range)	80.3 (10.3) 81 (67, 100)	75 (7.6) 74 (68, 83)
Height in cm	Mean (SD) Median (range)	173.9 (10.1) 173 (159, 198)	176.7 (3.8) 175 (174, 181)
Body mass index (BMI)	Mean (SD) Median (range)	26 (3.8) 25.5 (21.3, 34.6)	22 (2.8) 22.2 (19.1, 24.6)
Years since onset of LBP	Mean (SD) Median (range)	14.1 (10.3) 17 (1, 30)	
Duration of LBP episodes in days	Mean (SD) Median (range)	7.9 (11.8) 3.5 (1, 37)	

Footnote: For average duration of LBP episodes, 4 participants were unable to specify (n=9)

Appendix 3:10c. Participant characteristics drivers

		Before-work	After-work
RDQ	Mean (SD) Median (range)	2.7 (3.6) 1 (0, 14)	2.3 (3.3) 1 (0, 14)
SF-MPQ:			
pain rating index rank values	Mean (SD) Median (range)	0.8 (1) 1 (0, 4)	1.4 (2.5) 1 (0, 12)
visual analogue score (VAS) for level of pain 0-100mm	Mean (SD) Median (range)	7 (8.4) 4 (0, 33)	9.1 (14.9) 4.5 (0, 62)
present pain index	Mean (SD) Median (range)	0.6 (0.8) 0.5 (0, 3)	0.7 (0.7) 1 (0, 2)

Footnote: RDQ and SF-MPQ questions relate to the day of testing. RDQ scores are out of 23; see section 3.5.6.2 for information on scoring the SF-MPQ.

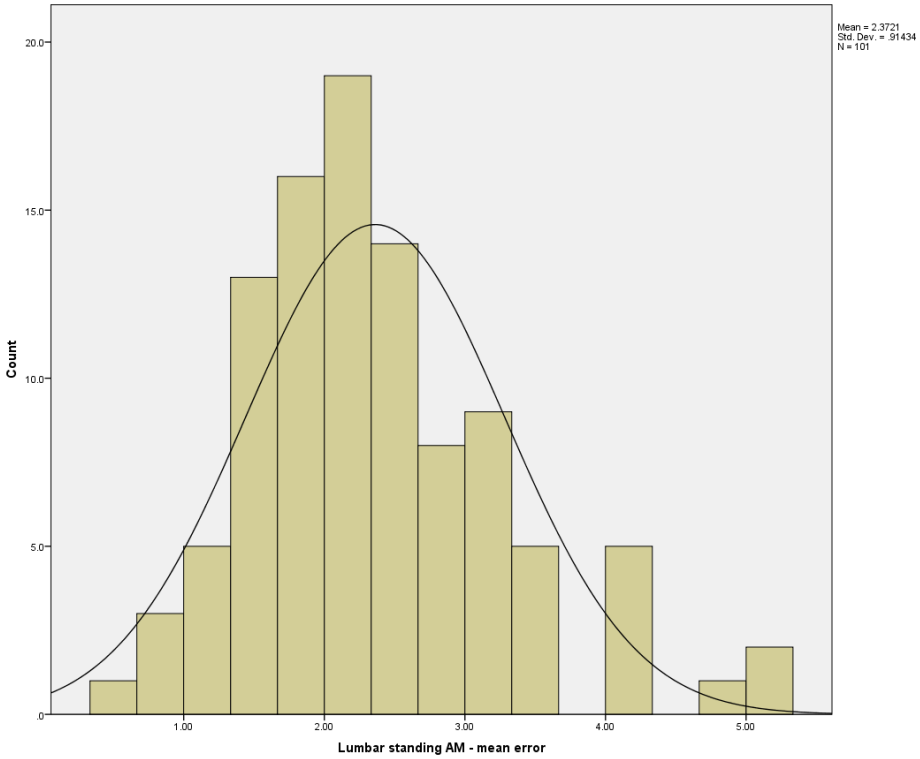
Appendix 3:11a. Self-reported disability (RDQ) & pain scores (SF-MPQ) for sedentary workers (n=26)

		Before-work	After-work
RDQ	Mean (SD) Median (range)	5 (4.8) 5 (0, 16)	5.4 (4.1) 5 (0, 13)
SF-MPQ:			
pain rating index rank values	Mean (SD) Median (range)	2.5 (2.5) 2 (0, 8)	3.6 (3.6) 2 (0, 12)
visual analogue score (VAS) for level of pain 0-100mm	Mean (SD) Median (range)	11.7 (11.4) 10 (0, 35)	24.5 (21.9) 20.5 (0, 73)
present pain index	Mean (SD) Median (range)	1 (0.7) 1 (0, 2)	1.2 (0.8) 1 (0, 3)

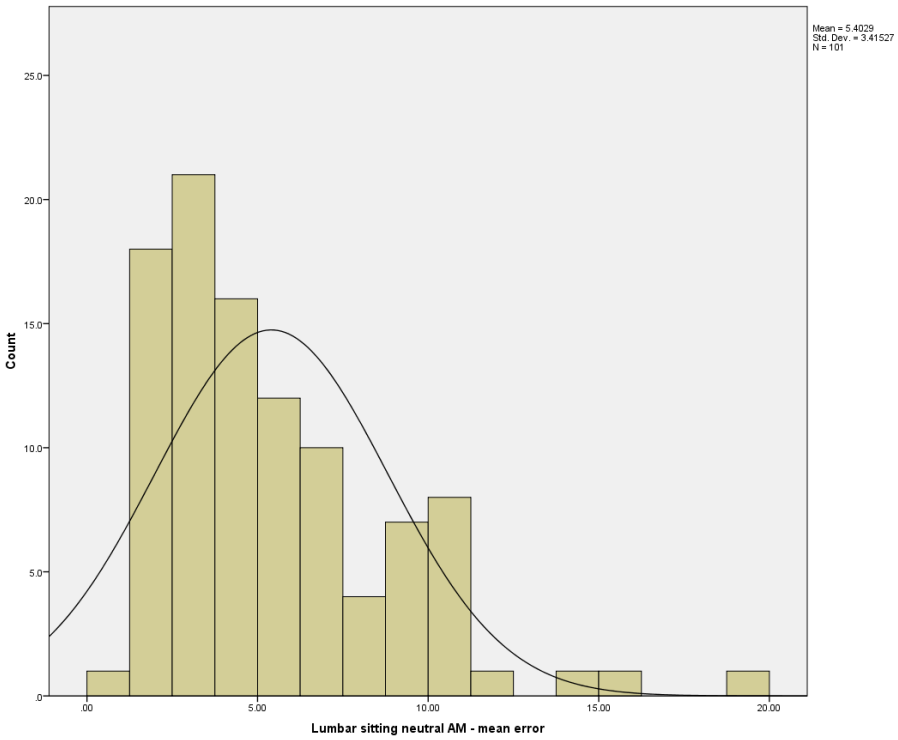
Appendix 3:11b. Self-reported disability (RDQ) & pain scores (SF-MPQ) for manual workers (n=22)

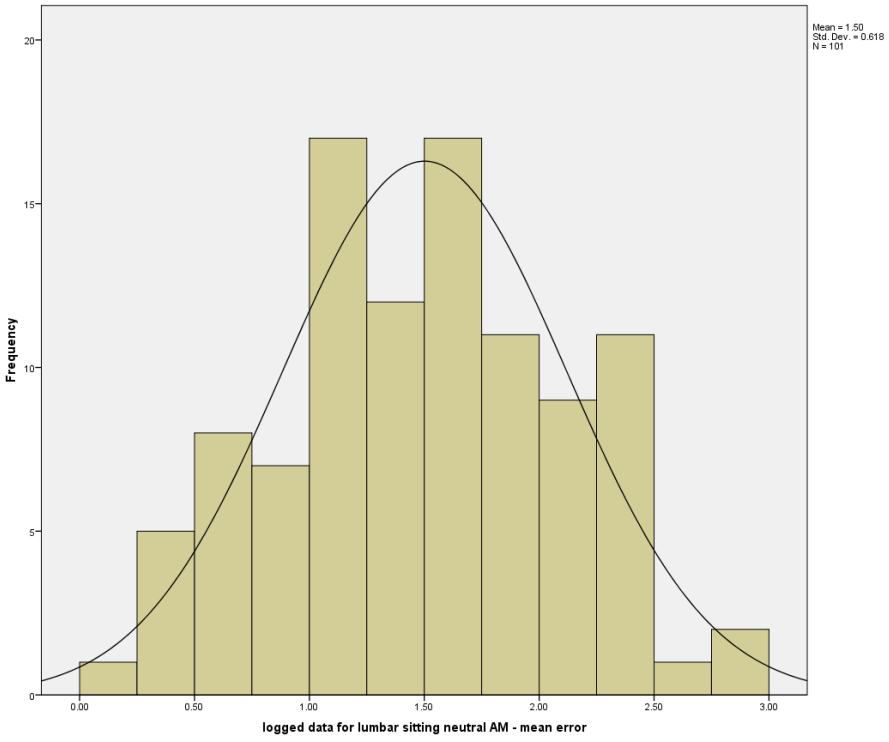
		Before-work	After-work
RDQ	Mean (SD) Median (range)	7 (5.8) 6 (0, 17)	8.5 (6.3) 8 (0, 19)
SF-MPQ:			
pain rating index rank values	Mean (SD) Median (range)	3.2 (3.6) 1 (0, 11)	6 (5.9) 5 (0, 19)
visual analogue score (VAS) for level of pain 0-100mm	Mean (SD) Median (range)	20.2 (20.3) 14 (2, 65)	26 (23.4) 18 (0, 67)
present pain index	Mean (SD) Median (range)	1.2 (0.7) 1 (0, 3)	1.4 (0.8) 1 (0, 3)

Appendix 3:11c. Self-reported disability (RDQ) & pain scores (SF-MPQ) for drivers (n=13)



Appendix 3:12. Example of data normally distributed





Appendix 3:13. Example of data log transformed with a normal distribution

NHS

National Research Ethics Service
SOUTHAMPTON & SOUTH WEST HAMPSHIRE
RESEARCH ETHICS COMMITTEE (A)

1ST Floor, Regents Park Surgery
Park Street, Shirley
Southampton
Hampshire
SO16 4RJ

Tel: 023 8036 2466
023 8036 2870
Fax: 023 8036 4110

Email: scsha.SWHRECA@nhs.net

VY/STA/hph

14 June 2007

Mr Dean R Phillips
Lecturer in Physiotherapy
University of Southampton
School of Health Professions & Rehabilitation Sciences
University of Southampton
Highfield, Southampton
SO17 1BJ

Dear Mr Phillips

Full title of study: **Is position sense during mid-range lumbo-pelvic movement altered in patients with chronic low back pain?**

REC reference number: **07/Q1702/52**

Thank you for your letter of 04 June 2007, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Vice-Chair.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

Ethical review of research sites

The Committee has designated this study as exempt from site-specific assessment (SSA). There is no requirement for other Local Research Ethics Committees to be informed or for site-specific assessment to be carried out at each site.

Conditions of approval

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Application		22 March 2007
Investigator CV : Mr D Phillips		01 March 2007
Protocol	1	01 March 2007
Covering Letter		22 March 2007

Appendix 4:1. Ethics approval letter (p1 of 3)

Letter from Sponsor		08 March 2007
Peer Review		14 June 2005
Compensation Arrangements		08 March 2007
Questionnaire: Appendix 3c	1	01 May 2007
Questionnaire: Appendix 3b	1	01 May 2007
Questionnaire: Appendix 3a	1	01 May 2007
Questionnaire: Appendix 11	2	24 May 2007
Sample Diary/Patient Card	1	01 May 2007
Advertisement: 5a	2	24 May 2007
Letter of invitation to participant	1	01 May 2007
GP/Consultant Information Sheets: Appendix 4	1	01 May 2007
GP/Consultant Information Sheets: Appendix 13	1	01 May 2007
Participant Information Sheet: Non LBP	1	25 May 2007
Participant Information Sheet: Patient	2	24 May 2007
Participant Consent Form: Non LBP	1	25 May 2007
Participant Consent Form: Patient	2	24 May 2007
Response to Request for Further Information		04 June 2007
Advertisement: 7c	2	24 May 2007
Advertisement: 7b	2	24 May 2007
Advertisement: 7a	2	24 May 2007
Advertisement: 6c	2	24 May 2007
Advertisement: 6b	2	24 May 2007
Advertisement: 6a	2	24 May 2007
Advertisement: 5c	2	24 May 2007
Advertisement: 5b	2	24 May 2007
Reply Slip for Future Research	1	25 May 2007
Letter from Lorraine Favaretto, Stoneham Centre		09 January 2007
Letter from Jay Cookson, RSH		05 February 2007
Confirmation of Data Protection		05 March 2007
Letter from Funders: Private Physiotherapy Educational Foundation		29 June 2005
Investigator CV: Professor M Hurley		01 March 2007

R&D approval

All researchers and research collaborators who will be participating in the research at NHS sites should apply for R&D approval from the relevant care organisation, if they have not yet done so. R&D approval is required, whether or not the study is exempt from SSA. You should advise researchers and local collaborators accordingly.

Guidance on applying for R&D approval is available from http://www.rdforum.nhs.uk/rdform.htm.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

Feedback on the application process

Now that you have completed the application process you are invited to give your view of the service you received from the National Research Ethics Service. If you wish to make your views known please use the feedback form available on the NRES website at:

https://www.nresform.org.uk/AppForm/Modules/Feedback/EthicalReview.aspx

We value your views and comments and will use them to inform the operational process and further improve our service.

07/Q1702/52	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project

Yours sincerely

Mrs Vikkie Yule
Vice-Chair

Email: scsha.swhreca@nhs.net

Enclosures: Standard approval

Copy to: Dr Martina Dorward
University of Southampton

UNIVERSITY OF
Southampton
School of Health Sciences

1st May 2007
Version 1
Ethics number: 07/Q1702/52

Dear Colleague

Title of Research Project: Posture & movement of the low back during sitting

I am writing to ask if you would be kind enough to inform people with low back pain (LBP) attending for treatment about this research. Fifty LBP participants and 50 non LBP participants aged between 18-60 years are to be recruited until 30th December 2008. LBP participants will have had non-specific LBP (with or without referral into the legs) lasting greater than 24hrs within the last 3 months and a previous history on at least one other occasion.

As you may be aware back pain is one of the costliest medical conditions in the UK and has been reported to affect 49% of the adult population in any one-year. This study will investigate whether poor sitting posture is found in LBP patients when compared to non pain participants. Further studies may investigate if improving awareness of sitting posture can alleviate some of the problems caused by LBP. The study has ethical approval from the Southampton and South West Hampshire Research Ethics Committee – study number: 07/Q1702/52

I will confirm eligibility with the participant prior to testing. Exclusion criteria are inability to perform the movements required for the low back sitting posture tests; severe LBP on day of testing (a score greater than 8 out of 10 on completing the pain questionnaire); inability to complete the questionnaires; unstable co-existing rheumatic, cardiovascular, respiratory, neurological, psychiatric or psychological disorders or medical conditions that might affect balance (Menniere's disease, vertigo, vestibular disturbances etc); use of systemic steroids, anticoagulants or medication that might affect balance; surgery to the back, pelvis or head; progressive nerve root signs and symptoms; cauda equina symptoms; non-mechanical pain.

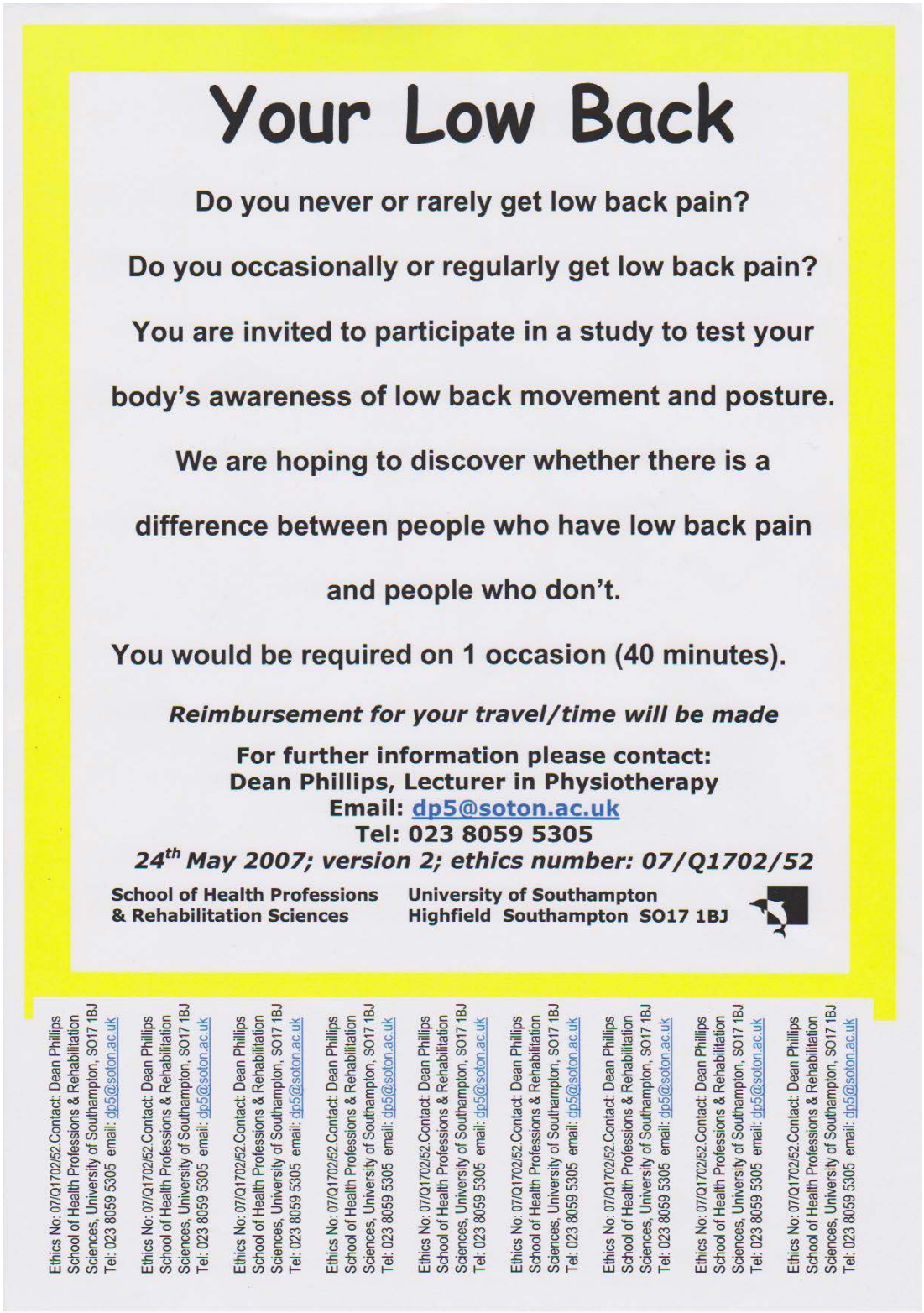
I would be grateful if you could display the attached posters and inform your staff of this research. A copy of the patient information sheet is attached for your reference and small credit card size contact slips are enclosed for potential volunteers. If you require further information about the project please contact Dean Phillips (Chief Investigator) Tel: 023 8059 5305; Email: dp5@soton.ac.uk Thank you for taking time to read this.

Yours sincerely

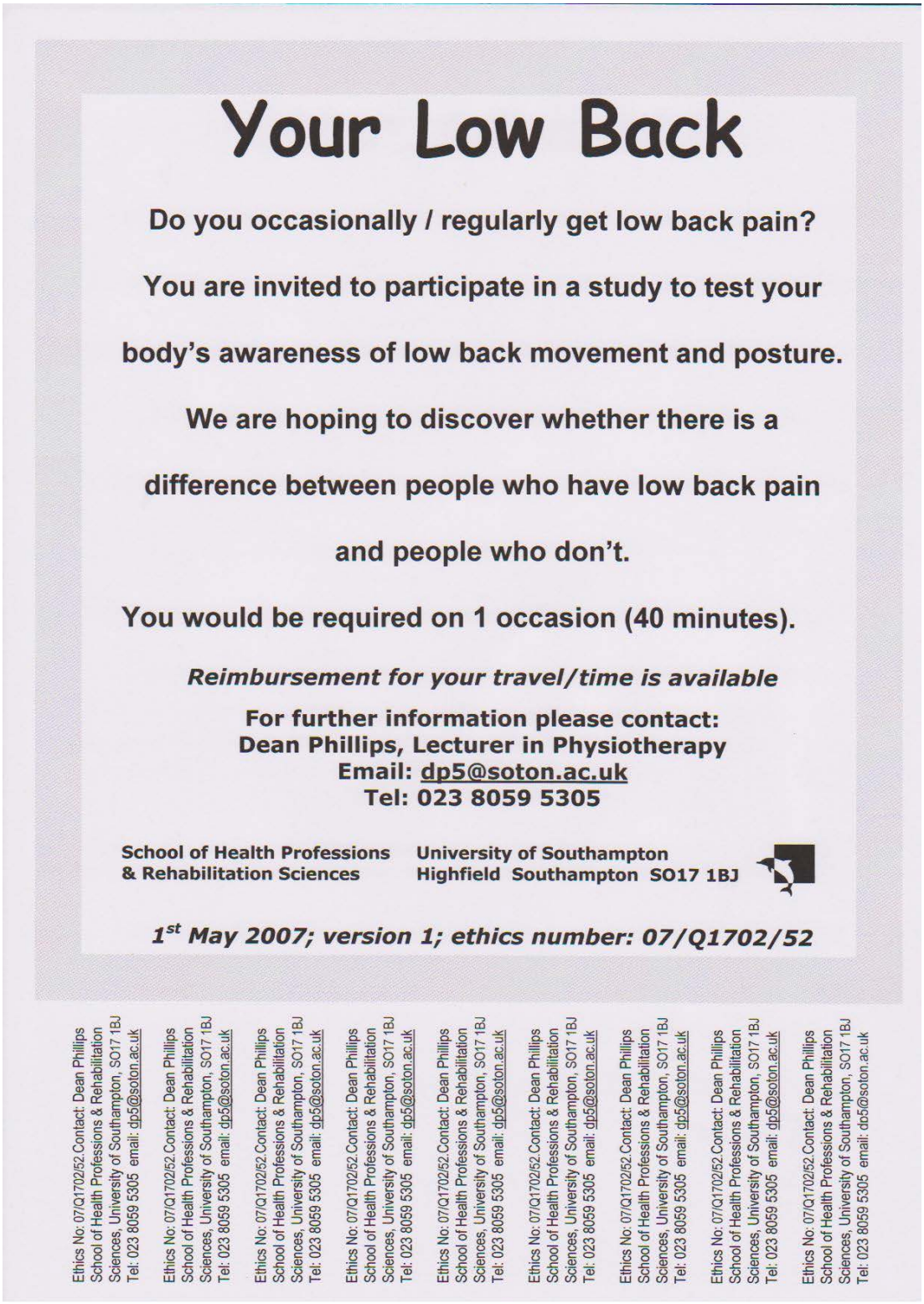
Dean Phillips
Lecturer in Physiotherapy

Building 45, School of Health Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2142 Fax: +44 (0)23 8059 5301 www.southampton.ac.uk/healthsciences

Appendix 4:2. Recruitment letter



Appendix 4:3a. Recruitment poster for people with and without LBP



Appendix 4:3b. Recruitment poster for people with LBP

Appendix 4:3c. Recruitment poster for people without LBP

Volunteers Required for Research Study

Have you never had or only very rarely had low back pain? Or do you occasionally or regularly get low back pain? Are you aged 18 – 60 years, male or female? You are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time is available if required. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton, Highfield, Southampton SO17 1BJ Tel: 023 8059 5305 *e-mail:* *dp5@soton.ac.uk*

Ethics submission number: 07/Q1702/52 *(version 1: 01.05.07)*

University of Southampton

Appendix 4:4a. Newspaper advert for people with and without LBP

Volunteers Required for Research Study

Do you occasionally or regularly get low back pain? Are you aged 18 – 60 years, male or female? You are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time is available if required. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton, Highfield, Southampton SO17 1BJ Tel: 023 8059 5305

e-mail: dp5@soton.ac.uk Ethics submission number: 07/Q1702/52 *(version 1: 01.05.07)*

Appendix 4:4b. Newspaper advert for people with LBP

Volunteers Required for Research Study

Have you never had or only very rarely had low back pain? Are you aged 18 – 60 years, male or female? You are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time is available if required. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton, Highfield, Southampton SO17 1BJ Tel: 023 8059 5305

e-mail: dp5@soton.ac.uk Ethics submission number: 07/Q1702/52 *(version 1: 01.05.07)*

Appendix 4:4c. Newspaper advert for people without LBP

Volunteers Required for Low Back Research Study

We are looking for males and females between 18 – 60 years, who get low back pain or never / rarely get low back pain. Whether or not low back pain is a problem for you, you are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time will be made. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton

e-mail: dp5@soton.ac.uk Tel: 023 8059 5305

Ethics submission number: 07/Q1702/52 (version 2: 24.05.07)

Appendix 4:5a. Advert in workplace publication for people with and without LBP

Volunteers Required for Low Back Research Study

We are looking for males and females between 18 – 60 years, who get occasional or regular low back pain. You are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time will be made. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton

e-mail: dp5@soton.ac.uk Tel: 023 8059 5305

Ethics submission number: 07/Q1702/52 (version 2: 24.05.07)

Appendix 4:5b. Advert in workplace publication for people with LBP

Volunteers Required for Low Back Research Study

We are looking for males and females between 18 – 60 years, who never or rarely get low back pain. Whether or not low back pain is a problem for you, you are invited to participate in a study to test your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain. You would be tested on 1 occasion for 40 minutes. Reimbursement for your travel/time will be made. For further information, please contact Dean Phillips, Lecturer in Physiotherapy, School of Health Professions & Rehabilitation Sciences, University of Southampton

e-mail: dp5@soton.ac.uk Tel: 023 8059 5305

Ethics submission number: 07/Q1702/52 (version 2: 24.05.07)

University of Southampton

Appendix 4:5c. Advert in workplace publication for people without LBP

UNIVERSITY OF Southampton
School of Health Sciences

1st May 2007
Version 1
Ethics number: 07/Q1702/52

Dear

Title of Research Project: Posture & movement of the low back during sitting

Thank you for your interest in the above study. Take time to decide whether or not you wish to take part (at least 24 hours). If after reading the attached information sheet you wish to be involved in the study please contact Dean Phillips
Tel: 023 8059 5305; Email: dp5@soton.ac.uk Thank you for taking time to read this.

Yours sincerely

Dean Phillips
Chief Investigator
Lecturer in Physiotherapy

Building 45, School of Health Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2142 Fax: +44 (0)23 8059 5301 www.southampton.ac.uk/healthsciences

Appendix 4:6. Cover letter for information booklet

Patient Information Sheet

24th May 2007; version 2

Ethics number: 07/Q1702/52

"Posture and movement of the low back during sitting"

Chief Investigator:

Dean Phillips

tel: 023 8059 5305

fax: 023 8059 5301

email: *dp5@soton.ac.uk*

School of Health Professions & Rehabilitation Sciences

University of Southampton

Highfield

Southampton

SO17 1BJ

You are invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please read the information carefully and discuss with others if you wish. Ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part; at least 24 hours.

What is the purpose of the study?

In any year 49% of adults have back pain lasting 24 hours or longer at a very high cost for the economy and health care. This study will investigate your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain.

Why have I been chosen?

Fifty people with LBP and fifty people without LBP are invited to take part in the study, allowing for comparison. LBP is defined as pain in the low back with or without pain in the buttocks or legs.

Do I have to take part?

No. It is up to you to decide whether or not to take part. If you do, you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care if you are receiving treatment for LBP. If you withdraw from the study, we will retain and use the data collected up to your withdrawal.

What will happen to me if I take part?

If you are interested in participating you will be telephoned to see if you are able to take part. If eligible you will be asked to attend a 40 minute session at the University of Southampton. Written consent will be required prior to volunteering. Comfortable trousers, tracksuit bottoms or

shorts will need to be worn and your mid to low back needs to be visible. A commonly used flexible measuring device will be attached to your low back with self-adhesive tape and also to a computer. You will then be asked to do two short tests in sitting, both involving forward and backward movements of your low back and measurements of your sitting posture. During testing, you will sit towards the edge of a slightly raised couch and be asked to close your eyes so the back of your legs, feet and sight do not help awareness of your sitting posture. You can open your eyes and put your feet on the ground at any time, and then return to testing. You will also be asked to complete three brief questionnaires related to back pain e.g. level of pain; how your pain may affect your work, social life and general health.

Most people will do this only once, but to confirm the accuracy of the measuring equipment, a small number of participants will be asked to perform the tests at two further sessions.

At the end of the study results will be compared between LBP and non pain participants.

Expenses and payments:

When attending for research testing you will be given a claim form to complete and the University will reimburse you £25 per visit to cover travel costs and to ensure you are not financially disadvantaged by your participation.

What do I have to do?

You should follow advice on how to care for your LBP given by your physiotherapist, GP or pharmacist. You can continue to attend for any treatment and take your regular medication or other prescribed or over-the-counter drugs. Unfortunately you will not be able to volunteer if you are currently taking part in another research project or have been involved in one in the last 3 months.

What are the possible benefits of taking part?

There will be no direct clinical benefit to you from taking part. The information we get might help improve the assessment and future treatment of people with LBP.

What are the possible disadvantages and risks of taking part?

Although highly unlikely there is a small risk of temporary soreness (e.g. mild aggravation of LBP) for 1-2 days following testing. The temporary soreness is a normal response to movement. If any soreness doesn't improve within 2 days or there is just a natural progression in your underlying LBP condition (which is possible with any LBP patient whether involved in this study or not) you can contact the Chief Investigator to discuss. If the soreness or progression is more than is normally expected, you will be asked to visit your GP.

Please let me know if you have a skin allergy to tape e.g. plasters, as it will not be possible for you to take part.

You will need to wear e.g. comfortable trousers, tracksuit bottoms or shorts and t-shirt to allow your low back to be seen. Please bring your own suitable clothing, although it will be provided if needed.

If you have private medical insurance you should check with the company, before agreeing to take part in the study, as participation may need to be reported. You will need to do this to ensure your participation will not affect your medical insurance.

What if there is a problem?

Complaints: If you have a concern about any aspect of this study, you should ask to speak with Dean Phillips, Chief Investigator, who will do his best to answer your questions (tel: 023 8059 5305). If you remain unhappy and wish to complain formally, you can do this through

Dr Martina Dorward, Research Governance Manager, Research Support Office, Building 27, Room 3043, University of Southampton, Highfield Southampton SO17 1BJ. Tel: 023 8059 8848/9. If your research testing is carried out at a Southampton City Primary Care Trust (SCPCT), out-patient physiotherapy department you can also complain formally through the NHS Complaints Procedure; details can be obtained from the hospital.

Harm: In the event that something does go wrong and you are harmed during the research study there are no special compensation arrangements. If you are harmed and this is due to someone's negligence, then you may have grounds for legal action against the University of Southampton, or Southampton City Primary Care Trust (depending on where your assessment took place). In both cases you may have to pay your own legal costs.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. To protect your identity all data will be coded and made anonymous. It will be used solely to fulfil the aims of this study. The data collected for the study may be looked at by authorised people from the University of Southampton and NHS Trust to check that the study is being carried out correctly. All will have a duty of confidentiality to you as a research participant and nothing that could reveal your identity will be disclosed outside the research site. All data will be stored securely for 15 years and then disposed of securely.

If you are currently receiving physiotherapy for LBP, your physiotherapist will be informed of your involvement in the study. Your GP will be informed about your involvement if you are currently receiving treatment from them for LBP.

What will happen to the results of the study?

It is the intention to publish the results, but you will not be identified in any report/publication. You will be sent a copy of a report that will be sent to all participants.

Who is organising and funding the research?

University of Southampton are sponsoring the research and it is funded by the Private Physiotherapy Educational Foundation (PPEF).

Who has reviewed the study?

This study has been reviewed by the Southampton and South West Hampshire Research Ethics Committee, University of Southampton and PPEF.

Contact for further information

If you have any questions or any concerns, please contact Dean Phillips (Chief Investigator) tel: 023 8059 5305

And finally...

Thank you for taking time to read this information. If you are happy to be involved please contact Dean Phillips Tel: 023 8059 5305; Email: dp5@soton.ac.uk

Participant Information Sheet
(Non LBP participants)

25th May 2007; version 1

Ethics number: 07/Q1702/52

"Posture and movement of the low back during sitting"

Chief Investigator:

Dean Phillips

tel: 023 8059 5305

fax: 023 8059 5301

email: dp5@soton.ac.uk

School of Health Professions & Rehabilitation Sciences

University of Southampton

Highfield

Southampton

SO17 1BJ

You are invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please read the information carefully and discuss with others if you wish. Ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part; at least 24 hours.

What is the purpose of the study?
In any year 49% of adults have back pain lasting 24 hours or longer at a very high cost for the economy and health care. This study will investigate your body's awareness of low back movement and posture. The research is hoping to discover whether there is a difference in this awareness between people who have low back pain and people who don't. This information may help in the future assessment and treatment of low back pain.

Why have I been chosen?
Fifty people with LBP and fifty people without LBP are invited to take part in the study, allowing for comparison. LBP is defined as pain in the low back with or without pain in the buttocks or legs.

Do I have to take part?
No. It is up to you to decide whether or not to take part. If you do, you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw at any time and without giving a reason. If you withdraw from the study, we will retain and use the data collected up to your withdrawal.

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shorts will need to be worn and your mid to low back needs to be visible. A commonly used flexible measuring device will be attached to your low back with self-adhesive tape and also to a computer. You will then be asked to do two short tests in sitting, both involving forward and backward movements of your low back and measurements of your sitting posture. During testing, you will sit towards the edge of a slightly raised couch and be asked to close your eyes so the back of your legs, feet and sight do not help awareness of your sitting posture. You can open your eyes and put your feet on the ground at any time, and then return to testing. You will also be asked to complete three brief questionnaires related to back pain to confirm you are not suffering LBP on the day of testing e.g. level of pain; how pain could affect work, social life and general health.

Most people will do this only once, but to confirm the accuracy of the measuring equipment, a small number of participants will be asked to perform the tests at two further sessions.

At the end of the study results will be compared between LBP and non pain participants.

Expenses and payments:

When attending for research testing you will be given a claim form to complete and the University will reimburse you £25 per visit to cover travel costs and to ensure you are not financially disadvantaged by your participation.

What do I have to do?

Unfortunately you will not be able to volunteer if you are currently taking part in another research project or have been involved in one in the last 3 months.

What are the possible benefits of taking part?

There will be no direct clinical benefit to you from taking part. The information we get might help improve the assessment and future treatment of people with LBP.

What are the possible disadvantages and risks of taking part?

Although highly unlikely there is a small risk of temporary discomfort in the low back for 1-2 days following testing. The temporary discomfort is a normal response to movement. If this doesn't improve within 2 days you can contact the Chief Investigator to discuss. If the discomfort is more than is normally expected, you will be asked to visit your GP.

Please let me know if you have a skin allergy to tape e.g. plasters, as it will not be possible for you to take part.

You will need to wear e.g. comfortable trousers, tracksuit bottoms or shorts and t-shirt to allow your low back to be seen. Please bring your own suitable clothing, although it will be provided if needed.

If you have private medical insurance you should check with the company, before agreeing to take part in the study, as participation may need to be reported. You will need to do this to ensure your participation will not affect your medical insurance.

What if there is a problem?

Complaints: If you have a concern about any aspect of this study, you should ask to speak with Dean Phillips, Chief Investigator, who will do his best to answer your questions (tel: 023 8059 5305). If you remain unhappy and wish to complain formally, you can do this through Dr Martina Dorward, Research Governance Manager, Research Support Office, Building 27, Room 3043, University of Southampton, Highfield Southampton SO17 1BJ. Tel: 023 8059 8848/9

Harm: In the event that something does go wrong and you are harmed during the research study there are no special compensation arrangements. If you are harmed and this is due to someone's negligence then you may have grounds for a legal action for compensation against University of Southampton, but you may have to pay your legal costs.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. To protect your identity all data will be coded and made anonymous. It will be used solely to fulfil the aims of this study. The data collected for the study may be looked at by authorised people from the University of Southampton and NHS Trust to check that the study is being carried out correctly. All will have a duty of confidentiality to you as a research participant and nothing that could reveal your identity will be disclosed outside the research site. All data will be stored securely for 15 years and then disposed of securely.

Your GP is not being informed about this project as there is no treatment intervention as part of the study.

What will happen to the results of the study?

It is the intention to publish the results, but you will not be identified in any report/publication. You will be sent a copy of a report that will be sent to all participants.

Who is organising and funding the research?

University of Southampton are sponsoring the research and it is funded by the Private Physiotherapy Educational Foundation (PPEF).

Who has reviewed the study?

This study has been reviewed by the Southampton and South West Hampshire Research Ethics Committee, University of Southampton and PPEF.

Contact for further information

If you have any questions or any concerns, please contact Dean Phillips (Chief Investigator) tel: 023 8059 5305

And finally...

Thank you for taking time to read this information. If you are happy to be involved please contact Dean Phillips Tel: 023 8059 5305; Email: dp5@soton.ac.uk

University of Southampton | School of Health Professions & Rehabilitation Sciences

Title of research study:
Posture & movement of the low back during sitting

1st May 2007; version 1; ethics number: 07/Q1702/52

Contact: **Dean Phillips**, SOHPRS,
University of Southampton, SO17 1BJ
Tel: 023 8059 5305 email: dp5@soton.ac.uk

Appendix 4:8. Credit card size details for people interested in volunteering

Version 2; 24.05.07; ethics number: 07/Q1702/52

Confidential personal data for the Research Project:
Posture & movement of the low back during sitting

Date .....
Name .....
DOB .....
Address .....
.....
.....
Postcode .....

Telephone Number (Home) .....
(Work) .....
(Mobile) .....
(email) .....

Key activities of your work or home role- please ✓		% split
Moving and handling inanimate objects	☐	
Driving	☐	
Computer work	☐	
Physical work	☐	
Other	☐	

Do you normally undertake any form of regular exercise	Yes/No
If 'yes' please state what exercise and frequency per week:	

Social activities e.g Dancing/ sailing/ golf /cycling	Yes/No
If 'yes' please state what activity and frequency per week:	

For LBP patients currently receiving treatment for their LBP:

GP Name .....
Address .....
.....
.....

Physiotherapist Name .....
Address .....
.....
.....

Appendix 4:9. Confirmation of eligibility (p1 of 4)

Baseline assessment to confirm eligibility for research

Subject number: _____

"Thank you for your interest in this study. Prior to volunteering I need to ask you some general questions to ensure your eligibility for the study." If the answer is yes to any questions need to put details over the page and indicate question number for ease of reference.

	Yes	No
1. Aged 18-60?	☐	☐
2. Are you currently a participant in a research study or have you been in the last 3 months?	☐	☐
3. Is your general health good – any operations or major illnesses?	☐	☐
4. Have you any poorly controlled medical or psychological conditions?	☐	☐
5. Any history of Menniere's disease, vertigo, vestibular disturbances that may affect balance?	☐	☐
6. Are you on any medication at the present time?-*if yes what dose/frequency & reason for use?*	☐	☐
7. Have you taken steroid or blood thinning tablets (anticoagulants)? -*if yes,when & how long for?*	☐	☐
8. Do you have any difficulty passing urine or opening your bowels?	☐	☐
9. Do you have any pins & needles or numbness between the legs?	☐	☐
10. Have you had any sudden, recent changes in your weight either loss or gain?	☐	☐
11. Have you had an episode of low back pain (LBP) in the last 3 months lasting > 24hrs?	☐	☐
12. Have you had a previous episode of LBP?	☐	☐
13. Have you ever sought medical advice for LBP?	☐	☐
14. Where is your pain? - *put on body chart*	☐	☐
15. Do you have any referral of pain into your buttocks, legs or feet? - *if yes put on body chart*	☐	☐
16. Is this referral of pain like a line and easily identified? - *if yes put on body chart*	☐	☐
17. Do you get any pins & needles or numbness? - *if yes put on body chart*	☐	☐
18. If you get pins & needles or numbness are these progressively worsening?	☐	☐
19. Does your LBP get better or worse with activity?	☐	☐
20. Does your LBP get better or worse with rest?	☐	☐
21. Do you have a skin allergy to adhesive tape e.g. plasters / elastoplast?	☐	☐

IF ELIGIBILITY IS CONFIRMED THEN CONSENT FORM IS TO BE SIGNED NOW
After consent form is signed volunteer participants to continue answering questions below

22. History of LBP (body chart complete over page; onset, duration of symptoms & previous management):

23. Episodes of LBP per year:_____ average duration of each episode (days):_____

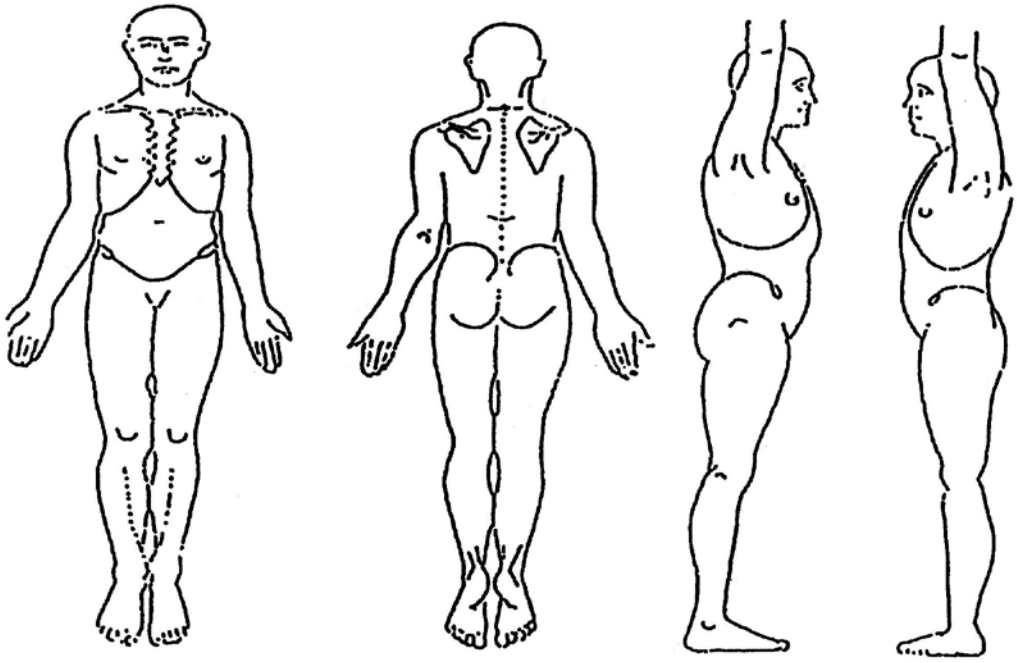
24. Height:_____cm

25. Weight:_____kg

Participants now complete study questionnaires & physical tests

Subject number: _____

Body Chart



Further information detailed for any questions (note question number)

Subject number: _____

Questionnaires completed

	Yes
1a. Pain	☐
1b. Is the pain score for today 8 or less	☐
2. Roland-Morris Disability Questionnaire (RDQ)	☐
3. Aberdeen LBP Questionnaire	☐

	Yes	No
Physical test 1 completed	☐	☐
Physical test 2 completed	☐	☐

Observations _____

_____

_____

If currently been treated by GP for LBP and have agreed in the consent form ☐
to their GP been informed of their participation in the study, then letter to be sent

If currently been treated by physiotherapist for LBP and have agreed in the ☐
consent form to their physiotherapist been informed of their participation in the study, then letter to be sent

Name of baseline assessor: Dean Phillips

Date.....

24th May 2007; version 2
Ethics number: 07/Q1702/52
Patient identification number for this research:

UNIVERSITY OF Southampton
School of Health Professions and Rehabilitation Sciences

CONSENT FORM

Title of Project: Posture and movement of the low back during sitting

Name of researcher: Dean Phillips

Please initial box

1. I confirm that I have read and understand the information sheet dated 24th May 2007 (version 2) for the above study. I have had the opportunity to consider the information; ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐
3. I understand that data collected during the study, may be looked at by responsible individuals from the University of Southampton, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data. ☐
4. I am currently receiving treatment from my GP for LBP and agree to them being informed of my participation in the study. ☐
5. I am currently receiving treatment from a physiotherapist for LBP and agree to them being informed of my participation in the study. ☐
6. I agree to take part in the above study. ☐
7. I am happy to perform the tests at two further sessions to help confirm the accuracy of the measuring equipment. ☐

Name of Patient	Date	Signature
Chief Investigator (also responsible for taking consent)	Date	Signature

When completed:
1 copy for participant; 1 copy for researcher file; 1 copy for physiotherapy notes if tested on NHS site.

School of Health Professions and Rehabilitation Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2142 Fax: +44 (0)23 8059 5301 www.sohp.soton.ac.uk

Appendix 4:10a. Consent form for people with LBP

UNIVERSITY OF Southampton
School of Health Sciences

25th May 2007; version 1
Ethics number: 07/Q1702/52
Participant identification number for this research:

CONSENT FORM
(non LBP participants)

Title of Project: Posture and movement of the low back during sitting

Name of researcher: Dean Phillips

Please initial box

1. I confirm that I have read and understand the information sheet dated 25th May 2007 (version 1) for the above study. I have had the opportunity to consider the information; ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that data collected during the study, may be looked at by responsible individuals from the University of Southampton, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data. ☐

4. I agree to take part in the above study. ☐

5. I am happy to perform the tests at two further sessions to help confirm the accuracy of the measuring equipment. ☐

Name of Patient	Date	Signature

Chief Investigator (also responsible for taking consent)	Date	Signature

When completed:

1 copy for participant; 1 copy for researcher file; 1 copy for physiotherapy notes if tested on NHS site.

Building 45, School of Health Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
Tel: +44 (0)23 8059 2142 Fax: +44 (0)23 8059 5301 www.southampton.ac.uk/healthsciences

Appendix 4:10b. Consent form for people without LBP

Version 1; 01.05.07; ethics number:07/Q1702/52

Date:_____

Subject number:_____

When your back hurts, you may find it difficult to do some things you normally do.

This list contains some sentences that people have used to describe themselves when they have back pain. When you read them, you may find that some stand out because they describe you ***today***. As you read the list, think of yourself ***today***. When you read a sentence that describes you today, put a tick against it. If the sentence does not describe you, then leave the space blank and go on to the next one. Remember only tick the sentence if you are sure it describes you today.

		Yes
1.	I stay at home most of the time because of my back	☐
2.	I change position frequently to try and get my back comfortable	☐
3.	I walk more slowly than usual because of my back	☐
4.	Because of my back I am not doing any of the jobs that I usually do around the house	☐
5.	Because of my back, I use a handrail to get upstairs	☐
6.	Because of my back, I lie down to rest more often	☐
7.	Because of my back, I have to hold on to something to get out of an easy chair	☐
8.	Because of my back, I try to get other people to do things for me	☐
9.	I get dressed more slowly then usual because of my back	☐
10.	I only stand for short periods of time because of my back	☐
11.	Because of my back, I try not to bend or kneel down	☐
12.	I find it difficult to get out of a chair because of my back	☐
13.	My back is painful almost all the time	☐
14.	I find it difficult to turn over in bed because of my back	☐
15.	My appetite is not very good because of my back pain	☐
16.	I have trouble putting on my socks (or stockings) because of the pain in my back	☐
17.	I only walk short distances because of my back	☐
18.	I sleep less well because of my back	☐
19.	Because of my back pain, I get dressed with help from someone else	☐
20.	I sit down for most of the day because of my back	☐
21.	I avoid heavy jobs around the house because of my back	☐
22.	Because of my back pain, I am more irritable and bad tempered with people than usual	☐
23.	Because of my back, I go upstairs more slowly than usual	☐
24.	I stay in bed most of the time because of my back	☐

Appendix 4:11. Roland Disability Questionnaire

Version 1; 01.05.07; ethics number: 07/Q1702/52

Date:_____ Subject number:_____

Clinical Back Pain Questionnaire

Please answer all questions.

1) In the last two weeks, for how many days did you suffer pain in the back or leg(s)?
Please tick one box.

None at all ☐
Between 1 and 5 days ☐
Between 6 and 10 days ☐
For more than 10 days ☐

2) **On the worst day during the last two weeks,** how many pain-killing tablets did you take?
Please tick one box.

None at all ☐
Less than 4 tablets ☐
Between 4 and 8 tablets ☐
Between 9 and 12 tablets ☐
More than 12 tablets ☐

3) Is the pain made worse by any of the following?
Please tick all boxes that apply to you.

Coughing ☐
Sneezing ☐
Sitting ☐
Standing ☐
Bending ☐
Walking ☐

4) Does lying down **ease** the pain?
Please tick one box.

Yes ☐
No ☐

5) **In your right leg,** do you have any pain in the following areas?
Please tick all boxes that apply to you.

Pain in the buttock ☐
Pain in the thigh ☐
Pain in the shin/calf ☐
Pain in the foot/ankle ☐

Appendix 4:12. Aberdeen Low Back Pain Scale (p1 of 4)

6) **In your left leg**, do you have any pain in the following areas?
Please tick all boxes that apply to you.

- Pain in the buttock ☐
- Pain in the thigh ☐
- Pain in the shin/calf ☐
- Pain in the foot/ankle ☐

7) Do you have any loss of feeling in your legs?
Please tick one box.

- No ☐
- Yes, just one leg ☐
- Yes, both legs ☐

8) **In your right leg**, do you have any weakness or loss of power in the following areas?
Please tick all boxes that apply to you.

- The hip ☐
- The knee ☐
- The ankle ☐
- The foot ☐

9) **In your left leg**, do you have any weakness or loss of power in the following areas?
Please tick all boxes that apply to you.

- The hip ☐
- The knee ☐
- The ankle ☐
- The foot ☐

10) If you were to try and bend forwards **without bending your knees**, how far down do you think you could bend before the pain stopped you?
Please tick one box.

- I could touch the floor ☐
- I could touch my ankles with the tips of my fingers ☐
- I could touch my knees with the tips of my fingers ☐
- I could touch my mid-thighs with the tips of my fingers ☐
- I couldn't bend forwards at all ☐

11) **On the worst night during the last two weeks**, how badly was your sleep affected by the pain?

Please tick one box.

Not affected at all ☐

I didn't lose any sleep but needed tablets ☐

It prevented me from sleeping but I slept for more than four hours ☐

I only had 2-4 hours sleep ☐

I had less than two hours sleep ☐

12) **On the worst day during the last two weeks**, did the pain interfere with your ability to sit down?

Please tick one box.

I was able to sit in any chair as long as I liked ☐

I could only sit in my favourite chair as long as I liked ☐

Pain prevented me from sitting for more than 1 hour ☐

Pain prevented me from sitting for more than 30 mins ☐

Pain prevented me from sitting for more than 15 mins ☐

Pain prevented me from sitting at all ☐

13) **On the worst day during the last two weeks**, did the pain interfere with your ability to stand?

Please tick one box.

I could stand as long as I wanted without extra pain ☐

I could stand as long as I wanted but it gave me extra pain ☐

Pain prevented me from standing for more than 1 hour ☐

Pain prevented me from standing for more than 30 mins ☐

Pain prevented me from standing for more than 15 mins ☐

Pain prevented me from standing at all ☐

14) **On the worst day during the last two weeks**, did the pain interfere with your ability to walk?

Please tick one box.

Pain did not prevent me walking any distance ☐

Pain prevented me walking more than 1 mile ☐

Pain prevented me walking more than ½ mile ☐

Pain prevented me walking more than ¼ mile ☐

I can walk but less than ¼ mile ☐

I was unable to walk at all ☐

15) In the last two weeks did the pain prevent you from carrying out your work/housework and other daily activities?

Please tick one box.

- No, not at all ☐
- I could continue with my work, but my work suffered ☐
- Yes, for one day ☐
- Yes, for 2-6 days ☐
- Yes, for more than 7 days ☐

16) In the last two weeks, for how many days have you had to stay in bed because of the pain?

Please tick one box.

- None at all ☐
- Between 1 and 5 days ☐
- Between 6 and 10 days ☐
- For more than 10 days ☐

17) In the last two weeks has your sex life been affected by your pain?

Please tick one box.

- Not affected by the pain ☐
- Mildly affected by the pain ☐
- Moderately affected by the pain ☐
- Pain prevents any sex life at all ☐
- Does not apply ☐

18) In the last two weeks, have your leisure activities been affected by your pain (including sports, hobbies and social life)?

Please tick one box.

- Not affected by the pain ☐
- Mildly affected by the pain ☐
- Moderately affected by the pain ☐
- Severely affected by the pain ☐
- Pain prevents any social life at all ☐

19) In the last two weeks has the pain interfered with your ability to look after yourself eg. washing, dressing etc.?

Please tick one box.

- Not at all ☐
- Because of the pain, I needed some help looking after myself ☐
- Because of the pain, I needed a lot of help looking after myself ☐
- Because of the pain, I could not look after myself at all ☐

Version 1; 01.05.07; Ethics number: 07/Q1702/52

Date:_____

Subject number:_____

For these next few questions, please circle the number which represents how your back pain has made you feel

for example:

0 - 1 - 2 - 3 - 4 (5) 6 - 7 - 8 - 9 - 10

In the past four weeks how much has your back pain interfered with your daily activities on a scale of 0–10, where 0 is no interference and 10 is unable to carry out any activities at all?

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

In the past four weeks, how much has back pain changed your ability to take part in recreational, social and family activities, where 0 is no change and 10 is extreme change.

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

In the past four weeks, how much has back pain changed your ability to work (including housework), where 0 is no change and 10 is extreme change?

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

How would you rate your back pain today on a 0–10 scale, where 0 is no pain and 10 is "as bad as a pain could be".

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

In the past four weeks how bad was your *worst* back pain on a 0–10 scale, where 0 is no pain and 10 is "as bad as a pain could be".

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

In the past four weeks on *average* how bad was your back pain on a scale 0–10, where 0 is no pain and 10 is pain "as bad as a pain could be".

0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10

Appendix 4:13. Modified Graded Chronic Pain Scale

Phillips DR (2009). Position sense in the low back. Physio First Cutting Edge Conference Day, Nottingham.

Phillips DR, Hurley MV, Mullee M (2005). Discrimination of the neutral low back sitting posture in people with and without low back pain, before and after a shift of work. BSR Annual Meeting and BHPR Spring Meeting, April 2005, *Rheumatology*, 44 (Supplement 1), pi159.

Phillips DR, Hurley MV, Davey CA, Mullee M (2004). Proprioceptive acuity of the lumbar spine in low back pain and non-low back pain subjects. BSR XXIst AGM and BHPR Spring Meeting, April 2004, *Rheumatology*, 43 (Supplement 2), pii151.

Phillips DR, Hurley MV, Davey CA (2004). Proprioceptive Acuity Of The Lumbar Spine In Low Back Pain And Non-Low Back Pain Subjects. Postgraduate Research Symposium, Graduate School for Health Sciences, King's College London, July 2004, p22.

Appendix 6:1. Publications & conference presentations in relation to PhD Thesis